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INSTRUCTION MANUAL

KEPCO®

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OPS

OPERATIONAL AMPLIFIER

MODULAR

design group

Model OPS 72–0.3B (C)

Serial No. E56314

INSTRUCTION MANUAL

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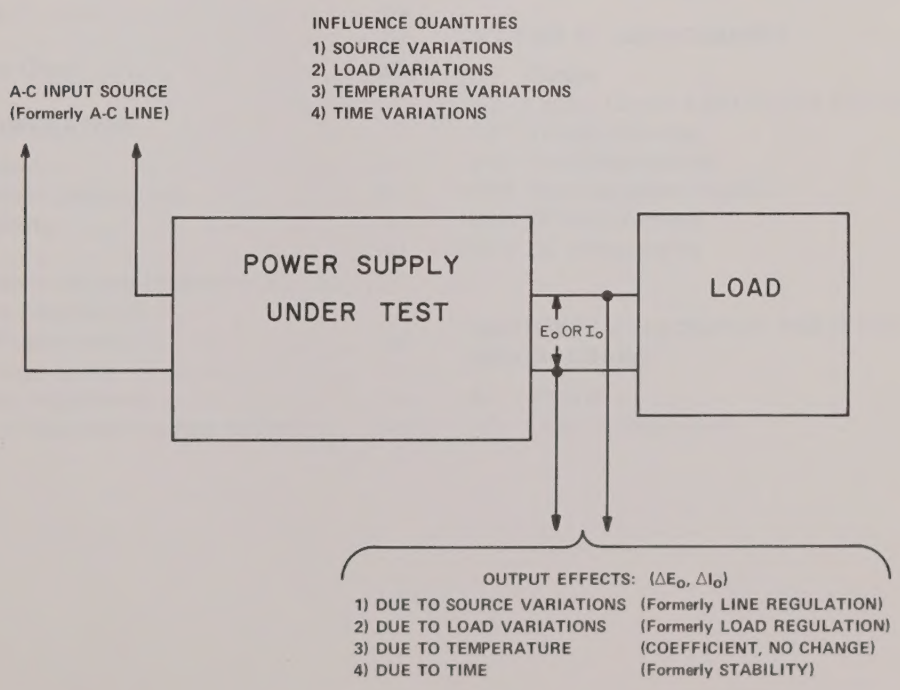
NEW IEC TERMINOLOGY FOR REGULATED

D-C POWER SUPPLIES

With the introduction of the 1970 Catalog (B-703), Kepco has adopted new technical terms recommended by the International Electrotechnical Commission (IEC). These terms replace or supplement previously used expressions, mainly to avoid difficulties in translation and prevent erroneous interpretations at home and abroad.

The IEC terminology will be introduced gradually into Kepco's technical literature. Equipment selected from the 1970 Kepco Catalog may therefore still have the old terminology in the instruction manual. To introduce the user to the new terms, however, and to coordinate the catalog specifications with those of the instruction manual, the new definitions are presented below.

As a beginning, Kepco will discontinue the use of the specifications entitled "Line Regulation" and "Load Regulation" because of the long standing (and misleading) connotation that a power supply regulates the line or the load. Instead, Kepco will follow the recommendation of the IEC and speak of the "Output Effects, caused by changes in the Influence Quantities." The "Output Effects" are specified as before, either as a percentage change referred to the maximum specified output voltage (E_O) or current (I_O) or as an absolute change ($\Delta E_O, \Delta I_O$) directly in millivolts or milliamperes or both. The "Influence Quantities" are the "Source Variations" (formerly A-C line variations), the changes in load, temperature or time as previously specified. The illustration below will clarify the use of the new terminology.



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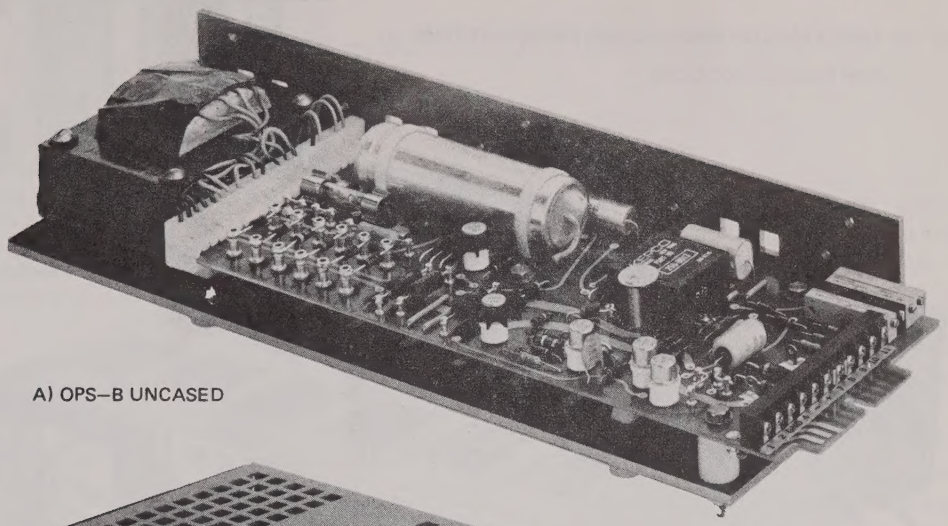
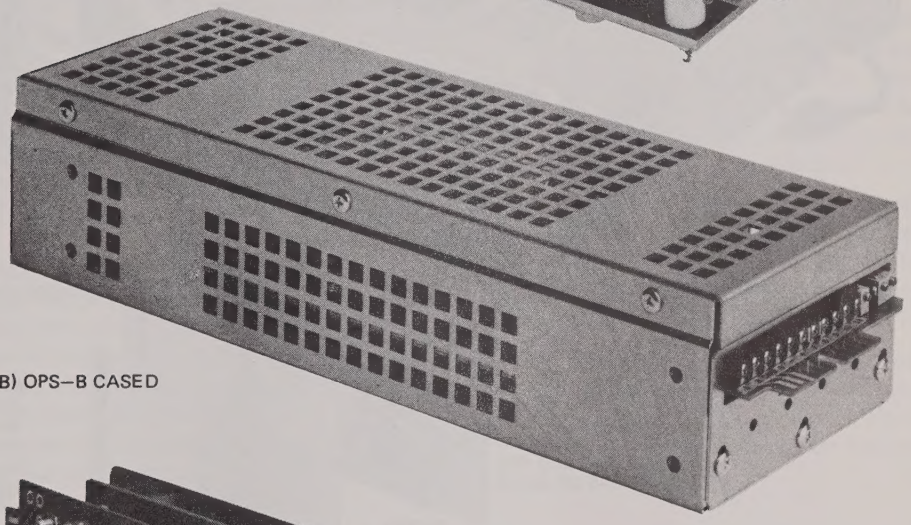
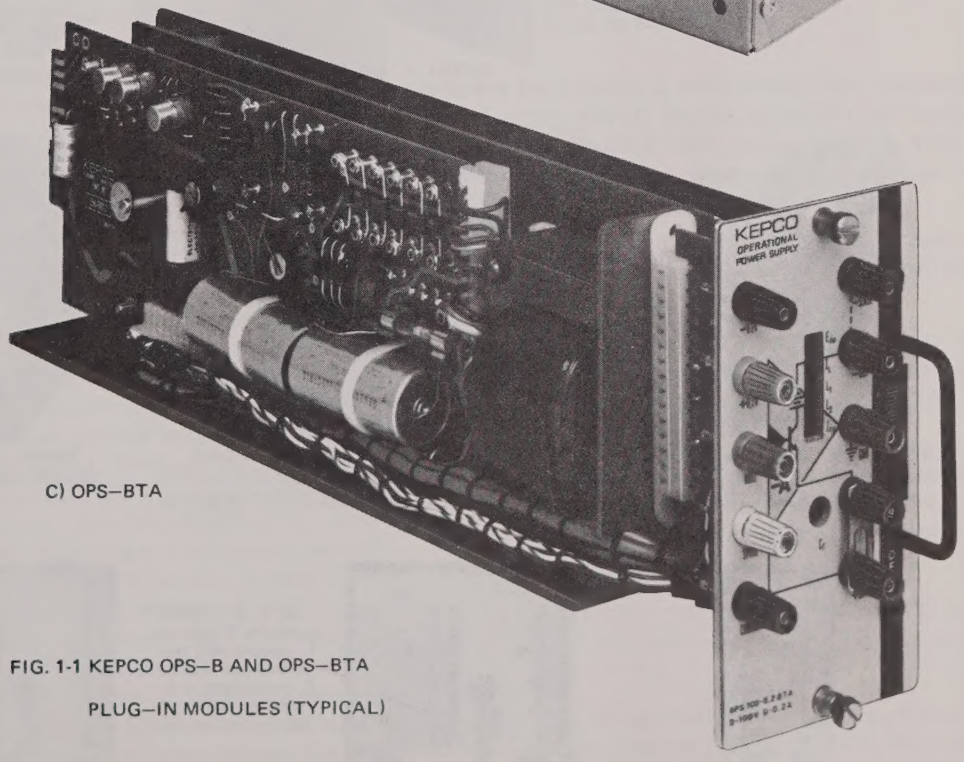


A) OPS–B UNCASED



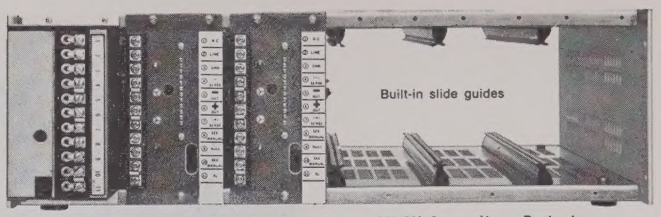
B) OPS–B CASED



C) OPS–BTA

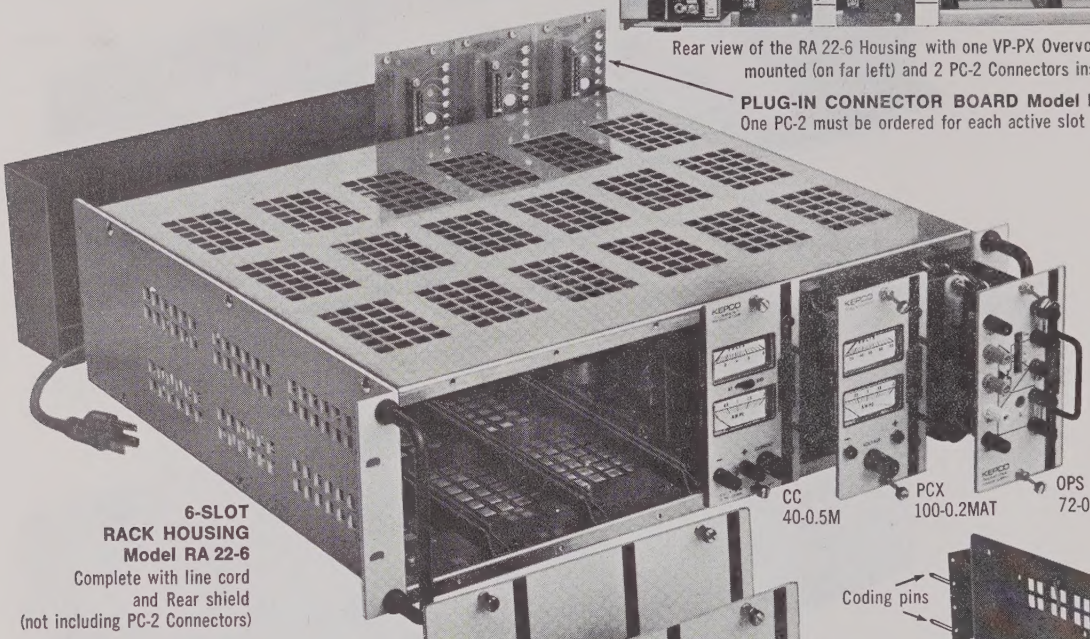
FIG. 1-1 KEPCO OPS–B AND OPS–BTA
PLUG–IN MODULES (TYPICAL)

FIG. 1-2 KEPCO ENCLOSURES AND HARDWARE SYSTEMS FOR PLUG-IN MODULES

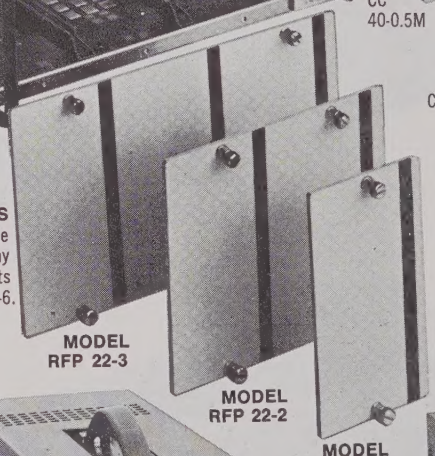


Rear view of the RA 22-6 Housing with one VP-PX Overvoltage Protector mounted (on far left) and 2 PC-2 Connectors installed

PLUG-IN CONNECTOR BOARD Model PC-2
One PC-2 must be ordered for each active slot in the RA 22-6.



6-SLOT RACK HOUSING Model RA 22-6
Complete with line cord and Rear shield (not including PC-2 Connectors)

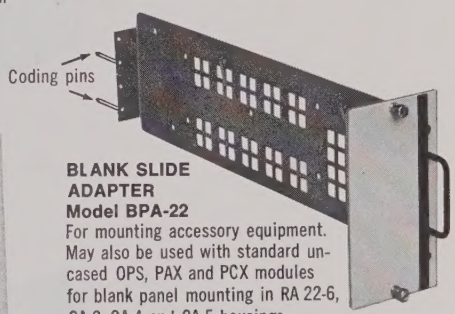


FILLER PANELS
(supplied without slide assembly and handle), may be used to fill unused slots in CA-3, CA-4, CA-5 and RA 22-6.

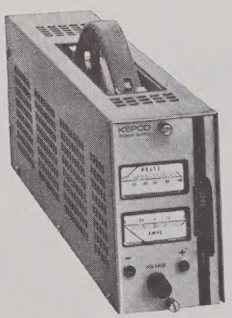
MODEL RFP 22-3

MODEL RFP 22-2

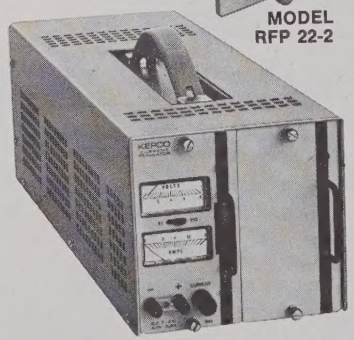
MODEL RFP 22-1



BLANK SLIDE ADAPTER Model BPA-22
For mounting accessory equipment. May also be used with standard uncased OPS, PAX and PCX modules for blank panel mounting in RA 22-6, CA-3, CA-4 and CA-5 housings.



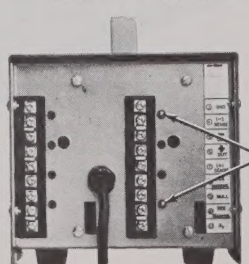
SINGLE UNIT HOUSING Model CA-3
Supplied complete with a built-in PC-2 connector. (shown with a PCX 100-0.2MAT plugged-in)



DOUBLE UNIT HOUSING Model CA-4
Supplied complete with a built-in dual PC-2 connector. (shown with a CC 40-0.5M and a BPA-22 plugged-in)

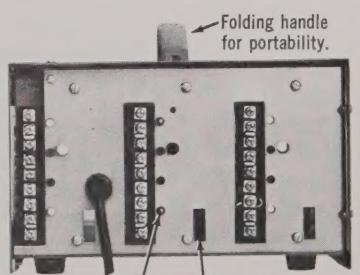
TRIPLE UNIT HOUSING Model CA-5
Supplied complete with a triple PC-2 connector.

Typical rear view of CA-3, showing access terminals and connector.



Typical rear view of CA-4, showing integral connector (Double PC-2) supplied.

All plug-in models and the BPA-22 are supplied with two coding pins that can be arranged in 6 different patterns to key the housing slots.



Typical rear view of CA-5, showing coding pins, connectors and line cord.

Slot provides access to internal adjustments in mounted supplies.

SECTION I – INTRODUCTION

1-1 SCOPE OF MANUAL

1-2 This manual contains instructions for the installation, operation and maitenance of the Series OPS–B and OPS–BTA Operational Power Supplies manufactured by Kepco Inc. Flushing, N.Y., N.Y.

1-3 GENERAL DESCRIPTION

1-4 The OPS–B and OPS–BTA Series represent a group of operationally programmable power supplies of modular construction. While the OPS–B group is delivered as a module with internal controls and rear terminations, the OPS–BTA Group is equipped with a functional front panel which contains all necessary operating terminations, recessed controls and AC power switch/indicator. The OPS–B and the OPS–BTA Series are identical with respect to their rear terminal configuration, electrical design and specifications, as are all models within the two series, except as noted in TABLE 1-1. Both, OPS–B and OPS–BTA Series are compatible with former Kepco Series OPS and OPS–TA. Since additional features have been added to the OPS–B/OPS–BTA Series however, the rear terminal arrangement has been changed on these models. In existing installations which previously used OPS/OPS–TA models, the wiring to the plug-in adaptors must be slightly altered to accomodate the new OPS–B/OPS–BTA Series (Refer to FIG. 2-1).

1-5 The OPS–B/OPS–BTA series of operational power supplies feature a plug-in type monolythic, integrated circuit amplifier, specifically adapted to the needs of an operational power supply. This amplifier provides a significant improvement over discrete component amplifiers, especially in such important parameters as the thermal stability and the temperature coefficient of the power supply. The high gain, plug-in amplifier is followed by a driver stage and a power booster to deliver the rated output current. Two built-in, well regulated reference sources (±6.2 V nominal) provide DC control current. The OPS–B/OPS–BTA operational power supply has a single ended, unipolar output, the positive (+) output terminal being common to either the inverting ("+in") or the non-inverting ("–in") input. Other features of the OPS–B/OPS–BTA Series include a sharp current-limit circuit, remote or locally adjustable in the range from 10 to 105% of the rated output current. The current limit circuit protects the load and renders the operational power supply completely short-circuit proof.

1-6 ACCESSORIES

1-7 The modular construction of the OPS–B/-OPS–BTA Series permits installation in a variety of mounting configurations (Refer to FIG. 1-2). Since the modules are supplied without AC line cords, AC input connections (and DC input/output connections in the case of OPS–B models) must be made by means of one of the rear termination methods listed below:

a) Using one of the mounting accessories listed below (Refer to paragraph 1-8), all of which are equipped with AC line cords and plug-in adaptors for OPS–B/OPS–BTA modules. The rear terminations of the module are transfered by the plug-in adaptor to the rear of the chosen case or rack-mount.

b) If none of the listed mounting accessories are used, the printed circuit rear connector of the OPS–B/OPS–BTA may be terminated with a mating jack to which all necessary connections must be wired.

c) OPS–B MODELS ONLY. All AC input, DC input/output and programming connections may be made at the rear barrier strip which duplicates the connections on the printed circuit connector.

1-8 ENCLOSURES AND MOUNTING HARDWARE FOR KEPCO MODULAR SUPPLIES (Optional, not supplied with power supply.) Refer to FIG. 1-2 for an illustration of the Kepco Hardware System.

a) MATING CONNECTOR, for uncased operation: KEPCO Model PC-1 or, METHODE Model CD-612-S-P7.

b) SINGLE SLOT HOUSING, accepts single OPS module and provides all necessary rear terminations. KEPCO Model CA3. (AC Line Cord included).

c) DOUBLE SLOT HOUSING. KEPCO Model CA4, accepts two OPS modules or mixtures.* Rear terminations provided. (AC Line Cord included)

d) TRIPLE SLOT HOUSING. KEPCO Model CA5, accepts three OPS modules or mix-

*NOTE: Multiple slot housings will accept a mixture of Kepco modular units (OPS–BTA, PCX–MAT) as well as blank-panel inserts such as BPA and RFP.

ture.* Rear terminations provided. (AC Line Cord included.)

e) RACK CABINET, KEPCO Model RA 22–6, accepts six OPS modules or mixture.* Each mounted unit needs a plug-in adaptor (f). (AC Line Cord included.)

f) PLUG-IN ADAPTOR, KEPCO Model PC–2, required for rack-mounting each plug-in module.

g) FRONT PANEL, KEPCO Model BPA–22, blank panel with slide bracket for fitting accessory equipment or other Kepco modular unit without front panel attachments.

h) FILLER PANELS
   1) KEPCO Model RFP 22–1, to cover one (1) empty slot in rack cabinet (RA 22–6) or one of the multiple slot housings (CA4,CA5).
   2) KEPCO Model RFP 22–2, to cover two (2) empty slots.
   3) KEPCO Model RFP 22–3, to cover three (3) empty slots.

*NOTE: Multiple slot housings will accept a mixture of Kepco modular units (OPS–BTA, PCX–MAT) as well as blank-panel inserts such as BPA and RFP.

1-9 SPECIFICATIONS, GENERAL

a) INPUT REQUIREMENTS: 105 V to 125 V AC or 210 V to 250 V AC, 50 to 440 Hz, single phase. See TABLE 1-1 for AC input current.

b) AMBIENT TEMPERATURE: −20°C to +65°C maximum.

c) STORAGE TEMPERATURE: −40°C to +85°C maximum.

d) ISOLATION: 500 volts maximum (DC or p-p) may be connected from chassis to either output terminal.

e) INTERNAL REFERENCE SUPPLIES: Precision regulated zener sources of plus (+) and minus (−) 6.2 volts (nominal) are provided internally and terminated at the rear as well as on front panel binding posts. The zener reference sources are temperature compensated and optimized for stability for a load current of 1 mA.

f) REFERENCE SPECIFICATIONS:
   1) STABILITY: Less than 0.005% variation over 8 hours at constant line, load and ambient temperature.
   2) TEMPERATURE COEFFICIENT: Better than 0.005% per°C.
   3) REGULATION: Less than 0.0001% variation from line changes over the range of 105 V to 125 V AC or 210 V to 250 V AC.

1-10 SPECIFICATIONS, AMPLIFIER MODE

a) INPUT, INVERTING: DC or AC voltage or current signals. POSITIVE input signal will produce NEGATIVE output, both with respect to the COMMON terminal.

b) INPUT, NON–INVERTING: DC voltage or current signals only. NEGATIVE input signal will produce NEGATIVE output, both with respect to the COMMON TERMINAL. (Maximum input voltage: ≈(−)8V)

c) OUTPUT: Unipolar, see TABLE 1-1 for maximum rated DC output.

d) COMMON TERMINAL: The positive error sensing terminal (normally linked to the positive output) represents the reference line common to inputs and output, to which all signals and DC voltages are referred.

e) SLEWING RATE (PROGRAMMING SPEED): Refer to TABLE 1-1.

MODEL	DC OUTPUT RANGE VOLTS	DC OUTPUT RANGE AMPS	OUTPUT IMPEDANCE OHMS DC	OUTPUT IMPEDANCE SOURCE INDUCTANCE	SLEWING RATE VOLTS/μ Sec.	MAX. INPUT AMPS. at 125 V AC
OPS 7–2B	0–7	0–2	0.0005	+15 μh	0.5	0.50
OPS 7–2BTA	0–7	0–2	0.0005	+150 μh	0.25	0.50
OPS 15–1.5B	0–15	0–1.5	0.001	+15 μh	1.0	0.65
OPS 15–1.5BTA	0–15	0–1.5	0.001	+150 μh	0.25	0.65
OPS 21–1B	0–21	0–1	0.0025	+15 μh	1.0	0.45
OPS 21–1BTA	0–21	0–1	0.0025	+150 μh	0.5	0.45
OPS 40–0.5B	0–40	0–0.5	0.008	+15 μh	1.5	0.40
OPS 40–0.5BTA	0–40	0–0.5	0.008	+150 μh	1.0	0.40
OPS 72–0.3B	0–72	0–0.3	0.025	+15 μh	1.5	0.45
OPS 72–0.3BTA	0–72	0–0.3	0.025	+150 μh	1.0	0.45
OPS 100–0.2B	0–100	0–0.2	0.050	+15 μh	2.0	0.45
OPS 100–0.2BTA	0–100	0–0.2	0.050	+150 μh	1.5	0.45

TABLE 1-1 OUTPUT SPECIFICATIONS OPS–B/OPS–BTA

f) FULL POWER FREQUENCY RESPONSE: See FIG. 1-3.

g) OUTPUT RIPPLE AND NOISE: <0.01% of peak output or 3 mV, whichever is greater.

h) REGULATION AND STABILITY
NOTE: (Refer to TABLE 1-2) The DC parameters are given as changes in offset voltage (E_{io}) and offset current (I_{io}) and referred to the null junction. To calculate their effect upon the output of the amplifier ΔE_{io} must be multiplied by the operational gain plus one ($R_f/R_i + 1$), while the effect of ΔI_{io} must be multiplied by the value of the feedback resistor (R_f).
Refer to Section IV of this manual for the definition of the offset terminology.

i) TRANSIENT RESPONSE:
1) VOLTAGE MODE (for step load current): Recovery is an exponential with a 50 μ sec. time constant.
2) CURRENT MODE (for step load voltage): Recovery takes place at the specified slewing rate.

j) CAPACITIVE LOADING: 0.001 μF maximum. A variable DC stability control (lag network) and an adjustable feedback capacitor is provided to operate into a limited range of load conditions.

k) OPEN LOOP dc GAIN: $<0.5 \times 10^6$ volts per volt.

SPECIFICATION	CHANGE IN OFFSET VOLTAGE (ΔE_{io})	CHANGE IN OFFSET CURRENT (ΔI_{io})
LINE (105 to 125V AC or 210 to 250V AC)	< 10 μV	< 2 nA
LOAD (No Load to Full Load)	< 200 μV	< 5 nA
TIME (8 Hours)	< 20 μV	< 2 nA
TEMPERATURE: (Per° C)	< 20 μV	< 5 nA

TABLE 1-2 OFFSET SPECIFICATIONS OPS–B/OPS–BTA

1-11 SPECIFICATIONS, PHYSICAL

a) Refer to Mechanical Outline Drawing, FIG. 1-4.

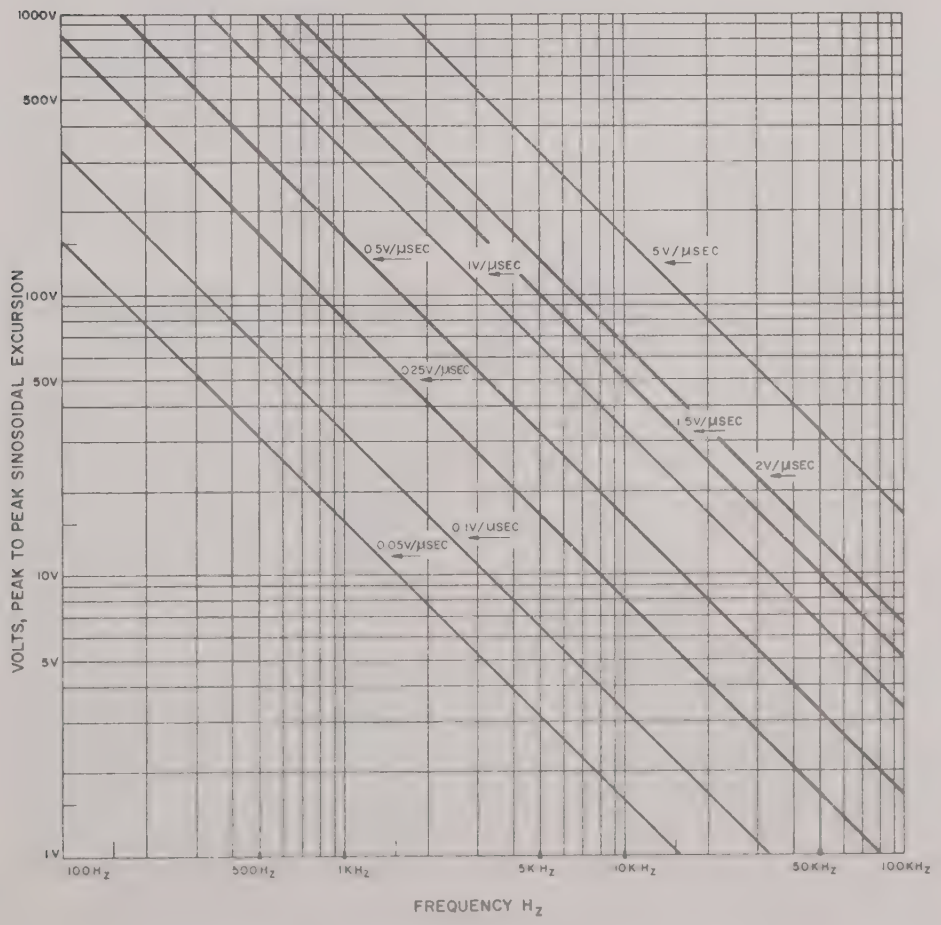
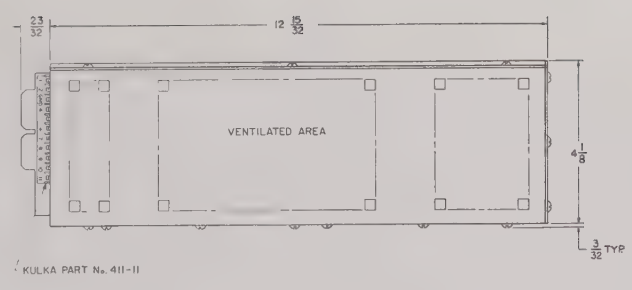
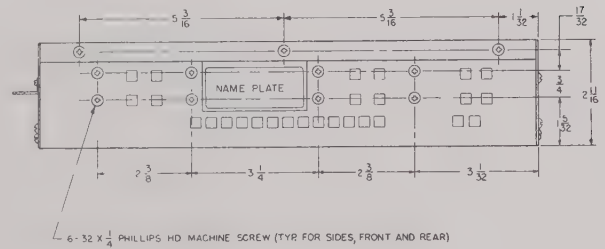
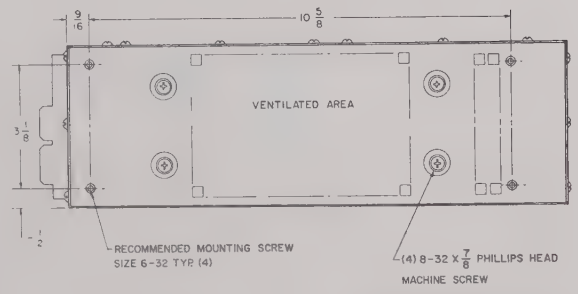


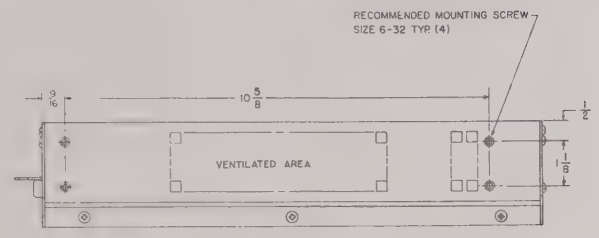
FIG. 1-3 OUTPUT VOLTAGE VS. SINE–WAVE FREQUENCY RESPONSE

CASED









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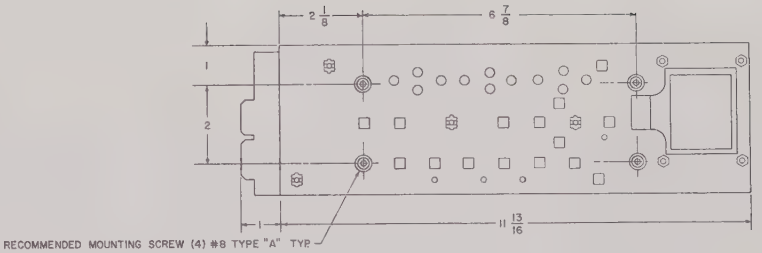
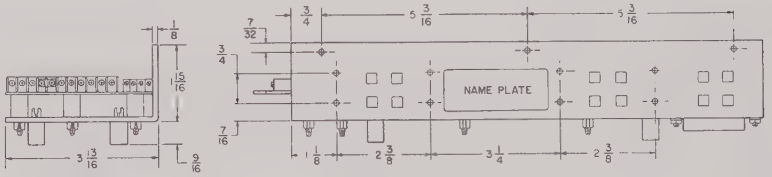
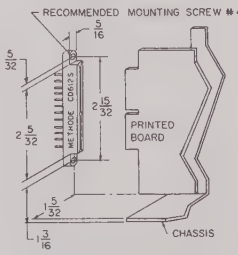
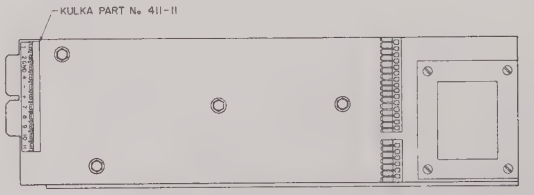






PC-1 CONNECTOR MOUNTING



FUSE DATA			
MODEL	FUSE SIZE	115 VAC	230 VAC
OPS21-1B	F1.0I	0.8 AMP.	0.4 AMP.
OPS40-0.5B	F1.0I	0.8 AMP.	0.4 AMP.
OPS7-2B	F1.0I	0.8 AMP.	0.4 AMP.
OPS15-1.5B	F1.0I	0.8 AMP.	0.4 AMP.
OPS72-0.3B	F1.0I	0.8 AMP.	0.4 AMP.
OPS100-0.2B	F1.0I	0.8 AMP.	0.4 AMP.

PC-1 CONNECTOR FUNCTION		TERMINAL BD. FUNCTION
NOTE: TERMINAL #7 NOT USED ON PC-1	1	1 } SWITCHED AC POWER
	2	2 }
	3	3 GND.
	4	4 (−) 6.2 V
	5	5 MINUS OUTPUT
	6	6 PLUS OUTPUT
	8	7 COMMON
	9	8 AMPL. INPUT, NON-INVERTING
	10	9 NULL AMPL. INPUT INVER.
	11	10 (+) 6.2 V
	12	11 REF. RESISTANCE
FOR ALTERNATE CONNECTIONS SEE KEPCO MANUAL		

NOTES:
1. THIS DRAWING USED FOR: OPS 21-1 B, OPS 40-0.5B, OPS7-2 B, OPS15-1.5B, OPS 72-0.3B, OPS100-0.2B.
2. MATERIAL, COVER #16 GAUGE ALUM. HEAVY ANODIZED, BLUE FINISH CHASSIS 1/8 THICK ALUM #3003-H14 HEAVY ANODIZED, BLUE FINISH
3. REFER TO KEPCO CATALOG FOR DETAILED SPECIFICATIONS

FIG. 1-4 MECHANICAL OUTLINE DRAWING, OPS–B GROUP

SECTION II – INSTALLATION

2-1 UNPACKING AND INSPECTION

2-2 This instrument has been thoroughly inspected and tested prior to packing and is ready for operation. After careful unpacking, inspect for shipping damage before attempting to operate. Perform the preliminary operational check as outlined in paragraph 2-11 below. If any indication of damage is found, file an immediate claim with the responsible transport service.

2-3 TERMINATIONS

a) OPS–BTA GROUP. All programming and load connections may be made either at the front panel binding posts (as shown in FIG. 2-2) or at the rear by means of a mating plug (Kepco Model PC–1) or a plug-in adaptor (Kepco Model PC–2)*. AC input connections are made at the rear (as shown in FIG. 2-3). All internal controls are recessed from the front panel and are accessible through the slot shown in FIG. 2-2.

b) OPS–B GROUP. All programming, load and AC input connections are made at the rear by means of a mating plug (Kepco Model PC–1) or a plug-in adaptor (Kepco Model PC–2)*. All internal controls are accessible from the rear. Their location is shown in FIG. 2-3.

*NOTE: The plug-in adaptor (Kepco Model PC–2) is part of all Kepco Housings and Rack-Mounts.

2-4 AC POWER REQUIREMENTS

2-5 The Model OPS–TA is normally delivered for operation on a single phase, 105 to 125 V AC line, 50 to 65 Hz. For operation on 210 to 250 V AC lines, the jumper connections on the main transformer (T201) must be changed as shown in FIG. 2-1.

2-6 PROCEDURE:

a) Disconnect power supply from line.

b) Remove bare wire jumpers between terminals (A) and (B) as well as (C) and (D).

c) Connect bare wire jumper between jumper terminals (B) and (C).

d) Replace 0.8 A fuse with 0.4 A (Slow Blow Type).

2-7 GROUNDING

2-8 For safety reasons it is imperative that the metal chassis is kept at ground potential. If a three-wire safety line cord and a properly grounded outlet is used, this is taken care of automatically. However, if only a two-wire line cord, or an adaptor for a three-wire line cord is used, the pigtail wire of the adaptor, or the metal chassis of the power supply must be returned to a good AC ground.

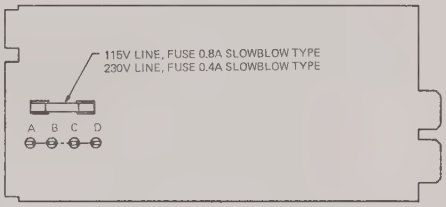


FIG. 2-1 CONVERSION TO 230V AC OPERATION

REFERENCE DESIGNATION OPS–B	REFERENCE DESIGNATION OPS–BTA	INTERNAL CONTROL	PURPOSE	ADJUSTMENT PROCEDURE
C10	C301	Feedback Capacitor	AC Stability Control	Par. 3-17
R15	R301	I_L Maximum	Overload Current Control	Par. 5-3
R21	R302	E_{io} Nulling	Zero Offset Voltage	Par. 3-10
R23	R304	Lag Network	AC Stability Control	Par. 3-19
R31	R305	I_{io} Nulling	Zero Offset Current	Par. 3-21

TABLE 2-1 INTERNAL CONTROLS

2-9 ISOLATION

2-10 The DC output terminals of the OPS–B/-OPS–BTA Operational Power Supply are isolated from the AC powerline and from the chassis. Since no DC connection to the chassis exists, either side of the output may be grounded, or a maximum of 500 V (DC or peak) can be connected between chassis and either output terminal.

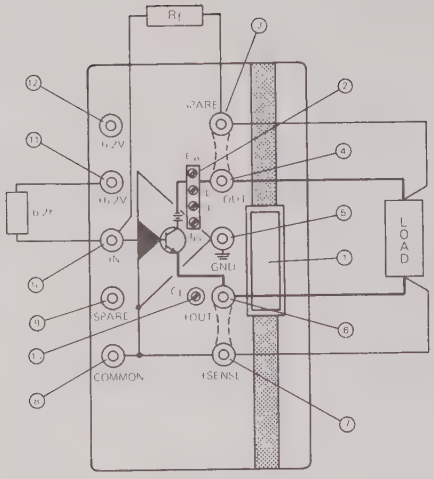


FIG. 2-2 FRONT PANEL TERMINATIONS, SHOWING EXTERNAL FEEDBACK RESISTOR (R_f) AND RECOMMENDED LOAD CONNECTION (OPS–BTA SERIES)

NO.	TERMINATION
1	AC POWER SWITCH AND PILOT LIGHT COMBINATION
2	INTERNAL ADJUSTMENTS (See Table 2-1)
3*	SPARE TERMINAL, USED FOR MINUS (–) ERROR SENSING, NORMALLY LINKED TO (–) OUTPUT. (REMOVABLE)
4	MINUS (–) OUTPUT TERMINAL. LOAD CONNECTION
5	CHASSIS CONNECTION. RETURN TO AC GROUND
6	PLUS (+) OUTPUT TERMINAL. LOAD CONNECTION
7*	PLUS (+) ERROR SENSING, NORMALLY CONNECTED TO (+) OUTPUT (REMOVABLE)
8	AMPLIFIER COMMON TERMINAL.
9	SPARE TERMINAL FOR INPUT COMPONENTS
10	AMPLIFIER INPUT TERMINAL (INVERTING)
11	POSITIVE (+) REFERENCE SOURCE, (+) 6.2 V (NOMINAL) IN RESPECT TO COMMON
12	NEGATIVE (–) REFERENCE SOURCE, (–) 6.2 V (NOMINAL) IN RESPECT TO COMMON
13	FEEDBACK CAPACITOR

*NOTE: FOR OPERATION WITHOUT ERROR SENSING, THE LINKS BETWEEN THE OUTPUT AND SENSING TERMINALS MUST BE CLOSED EITHER AT THE FRONT PANEL OR AT THE REAR. ERROR SENSING MAY BE USED FROM THE FRONT OR THE REAR TERMINALS.

TABLE 2-2 FRONT PANEL TERMINATIONS, OPS–BTA SERIES

2-11 OPERATIONAL CHECK

2-12 A simple electrical check-out after unpacking and before permanent installation is advisable to ascertain whether the instrument has suffered damage during shipment. Connect AC line input as shown in FIG. 2-3. Connect feedback resistor and load either to the front panel (See FIG. 2-2, for OPS–BTA Models only) or at the rear (See FIG. 2-3). Close link between terminals (10) and (11), or (in the case of an OPS–BTA Model) connect an external reference resistor of approximately 6K ohms from the "(+) 6.2V" reference voltage to the "–in" terminal. Either method provides a control current of about 1 mA. The output voltage of the OPS–B/OPS–BTA will then be approximately equal to the value of the feedback resistor times 1mA: [E_O(volts) ≈ R_f x 1 mA]. If a variable resistor is selected for R_f, its value in kilohms equal to the maximum rated voltage of the unit under test, the output voltage may be varied from ≈ zero to E_O max. Connect a suitable voltmeter across the output and apply AC line power. Observe output voltage. This completes the preliminary check-out.

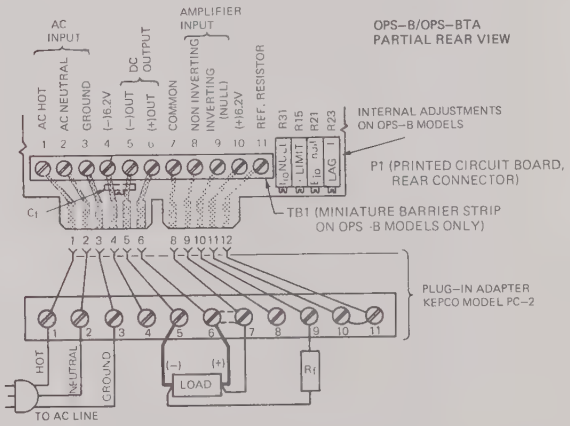


FIG. 2-3 REAR TERMINATIONS, EXTERNAL FEEDBACK RESISTOR (R_{VC}) AND RECOMMENDED LOAD CONNECTIONS.

SECTION III – OPERATION

3-1 BEFORE TURN-ON

3-2 The rear printed circuit connector (P1) of the OPS–B/OPS–BTA Operational Power Supplies must be terminated using one of the methods described in paragraph 1-6 (Section I) and as illustrated below (Refer to FIG. 3-1).

3-3 LOAD AND INPUT CONNECTIONS

3-4 The load, input and feedback components may be connected at the rear-terminals or at the front panel binding posts (OPS–BTA Models only). Load wires should be of the largest practicable diameter to reduce voltage drops due to load current, and should be twisted to keep the output impedance as low as possible. Specified performance directly at the load requires the use of the "Error Sensing" technique as described below.

3-5 REMOTE ERROR SENSING

3-6 This technique compensates for voltage drops in the load connecting wires. The "common" terminal (+ sense) and the feedback return (– sense) normally connected to the output terminals, are disconnected and placed directly at the load (See FIG.'s 2-2 and 2-3). Up to 0.5V drop across each loadwire can be compensated using this method.

NOTE: On OPS–BTA Models, "Error Sensing" may be used from the front panel terminals or from the rear. In the latter case, the front links between output and sensing links must be removed. Error sensing wires may be of moderate diameter, but should be twisted and shielded.

3-7 TURN–ON

a) OPS–BTA Models Only. AC power is turned on by activating the front panel slide switch. Line power "on" is indicated by the energizing of the neon type bulb which is part of the switch assembly.

b) OPS–B Models. An AC power switch should be connected into the "HOT" AC terminal (Refer to FIG. 2-3). DC output is available immediately after turn-on. Before measurements or critical applications, a warm-up period of 30 minutes is recommended to allow all internal components to assume thermal equilibrium.

3-8 INTRODUCTION TO REMOTE PROGRAMMING

3-9 GENERAL.

a) DIAGRAMS. Application-and test set-up diagrams in this section show the symbolic representation of the OPS–B/OPS–BTA Operational Power Supply. TERMINAL NUMBERS correspond with the adaptor rear terminal designations on single or multiple unit cases and rack-cabinets. Terminal NOMENCLATURE refers to the front panel markings on OPS–BTA Models.

NOTE: The terminal marked "SPARE" is provided for the connection of the feedback resistor and is available on the front panel of the OPS–BTA Series only.

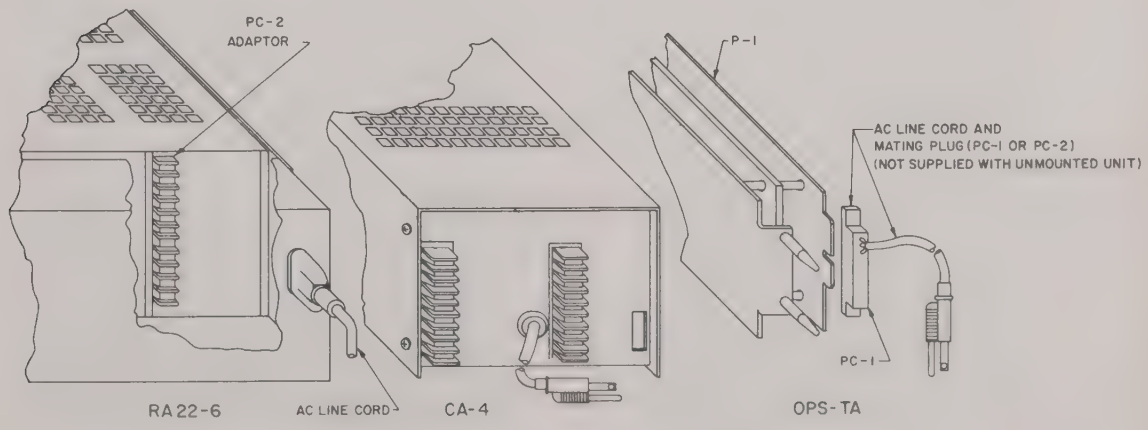


FIG. 3-1 INSTALLATION OPTIONS, OPS–B/OPS–BTA

Each diagram shows the external programming components (and the load) OUTSIDE of the dashed line surrounding the symbolic diagram of the OPS–B/OPS–BTA. AC line connections have been omitted from the diagrams to simplify the representation.

b) GROUNDING. Although the positive output (common) in all diagrams is shown grounded, the negative output may be grounded as well, or the output may be left ungrounded with a slight increase of the ripple and noise level. All programming set ups must have a SINGLE GROUND POINT, to which all input source and instrument grounds must be connected. Multiple ground points will produce ground loops which result in excessive ripple and noise levels.

c) EXTERNAL PROGRAMMING RESISTORS. External programming resistors should be high quality, wire-wound units, with temperature coefficients of 20 parts per million or better. Their wattage rating must be at least 10 times the actual power dissipated. Although the control current through these resistors is normally very low, an error current exists when large voltage excursions are programmed. The magnitude of this error current equals the change in output voltage, divided by the final resistance of the programming resistor. If, for example, the voltage step is from 50 volts to zero ($\Delta E_O = 50$ V) and the final resistance of the programming resistor is $\Delta R_{VC} = 2$ ohms, $I_{peak} = 25$ A! The duration of the peak error current depends upon the size of the output capacity. I_{peak} decays exponentially as the output voltage assumes the final value.

d) INPUT OR REFERENCE SOURCES. External programming or reference sources should have specifications equal or better than the OPS–B/OPS–BTA Power Supply to be programmed.

e) EXTERNAL SWITCHES. If step-switch devices are used in resistance programming, they must be of the "make before break" variety to avoid programming infinity.

f) EXTERNAL LEADS. Shielded leads should be used for all external connections, except for load wires, which should be of the largest wire diameter practical and twisted, to reduce load inductance. (Excessive load inductance causes deterioration of transient response time) Load capacitance should be minimized as far as possible, since excess capacity limits high frequency bandwidth and thereby reduces the slewing rate of the OPS–B/OPS–BTA power supply.

3-10 ZEROING THE AMPLIFIER FOR PRECISION PROGRAMMING

3-11 The initial offset voltage and offset current present at the amplifier input should be carefully zeroed before programming. Built-in trim rheostats are provided in the OPS–B/OPS–BTA for this purpose. The procedure and test set-ups described below should be part of each application, especially those requiring high programming accuracy.

3-12 PROCEDURE, OFFSET NULLING

a) Equipment Required:
   1) Sensitive null-meter, MILLIVAC Model MV-07A or equivalent, or Oscilloscope, TEKTRONIX MODEL 502A: (M1)
   2) Single pole switch (S1).
   3) Resistance Decade box (Megohm range) or single resistor (R_f).

b) Connect test set-up as shown in FIG. 3-2.

c) Offset Voltage Nulling:
Close S1. Locate offset voltage zero control (Refer to FIG. 2-2 or 2-3 marked: "E_{io}"). Adjust control until null detector (M1) reads precisely zero. The adjustment may shift slightly as the OPS–B/OPS–BTA and the null detector reach thermal equilibrium. Repeat adjustment as necessary.

d) Offset Current Nulling:
Open S1. Retain the test set-up in FIG. 3-2. Locate offset current zero control (Refer to FIG.'s 2-2, 2-3 marked "I_{io}") and set to exact zero volts as read-out on M1. Increase sensitivity of adjustment by increasing the resistance (R_f) placed across the feedback terminals. Repeat adjustment as necessary.

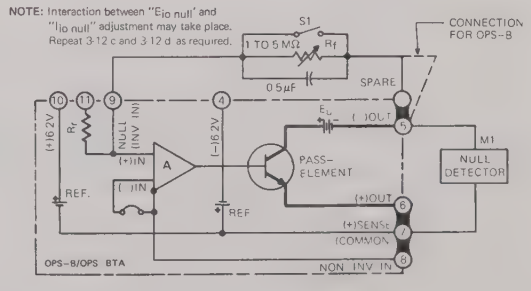


FIG. 3-2 TEST SET–UP FOR OFFSET NULLING

e) The adjustment for nulling I_{io} becomes more critical as the feedback resistance is raised. With care, the offset current can be reduced to a few nano amperes. (1 nano ampere across 5 megohm represents an output voltage of 5 mV as read out on M1) Offset current nulling results in raising the input impedance looking into the feedback terminals. This becomes important in applications where the OPS–B/OPS–BTA is connected as an impedance transformer, since the feedback terminals represent the "input" of the circuit. Impedance in this case will be directly proportional to the residual offset current. With careful adjustment, Z_{in} can be raised to 10^7 or 10^8 ohms.

3-13 REMOTE PROGRAMMING

3-14 GENERAL. Once the offsets have been properly nulled and the device has reached thermal equilibrium, the necessary operational gain can be determined and the circuit components may be calculated for the application at hand. Since the applications will vary widely, component selection can be demonstrated on a few examples only. For further circuit information and many other possible applications, please consult the Kepco "Power Supply Handbook" and the standard texts on operational amplifier applications.

3-15 RESISTANCE PROGRAMMING. The output voltage of the OPS–B/OPS–BTA can be controlled by means of a variable feedback resistance connected between the appropriate terminals. This resistance may be fixed, continuously adjustable or step controlled, or it may be a combination of these. The value of the output voltage is given by:

$$E_o = R_f \frac{E_r^*}{R_r}$$

where the ratio E_r/R_r constitutes the control current, $I_b = E_r/R_r$. The necessary control current ($I_b = E_r/R_r$) may be generated by using the internal reference source (E_r = 6.2V nominal). Since the optimum control current value from this zener regulated voltage is 1 mA, the reference resistor (R_r) should be 6.2K ohm. A fixed, 5.7K ohm resistor is provided (R28) which in conjunction with an external trim rheostat is connected as shown (Refer to FIG. 3-3), so that precisely 1 mA can be adjusted, resulting in a programming ratio of 1000 ohms/volt i.e. for each 1000 ohms of feedback resistance (R_f), one volt will appear at the output.

*NOTE: Refer to Section IV "THEORY OF OPERATION" for the derivation of the transfer function.

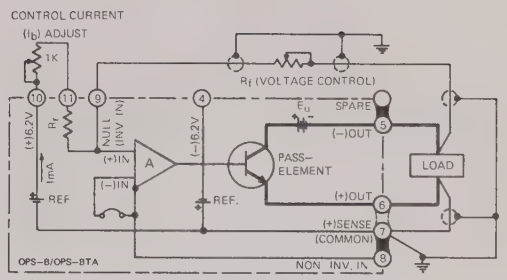


FIG. 3-3 RESISTANCE PROGRAMMING

3-16 PROCEDURE (Refer to FIG. 3-3)

a) Determine value of programming resistor (R_f) for output voltage desired.

b) Using two-wire shielded cable, connect R_f to either front (on OPS–BTA Models Only) or rear terminals as shown. Connect shield to signal ground.

c) The output voltage will vary from zero to: (1 mA) x (R_{vc}), as R_{vc} is adjusted from zero to its maximum value. Should any overshoot be observed when high speed programming into loads not purely resistive, refer to the following paragraph for lag network adjustment procedures.

3-17 AC STABILITY ADJUSTMENTS

3-18 The underdamped characteristics of an operational power supply or amplifier may give rise to "ringing", "overshoot" or oscillation at the output, especially when high speed programming into loads not purely resistive. In the OPS–B/OPS–BTA provisions have been made for stabilizing the amplifier for a fairly large range of load conditions. A lag network at the input and a trimmer capacitor (C_f) across the feedback terminals may be individually adjusted for each load condition. The adjustments are accessible through the slot in the front panel (OPS–BTA MODELS) or from the rear (OPS–B MODELS). Their location is shown in FIG.'s 2-2 and 2-3.

3-19 The AC characteristics of the OPS–B/OPS–BTA are optimized at the factory by programming the input with a square wave and working into a resistor load, using a gain ratio of unity. ($G = R_f/R_i = 1$). The factory procedure may be readily duplicated using a test set-up as shown in FIG. 3-4.

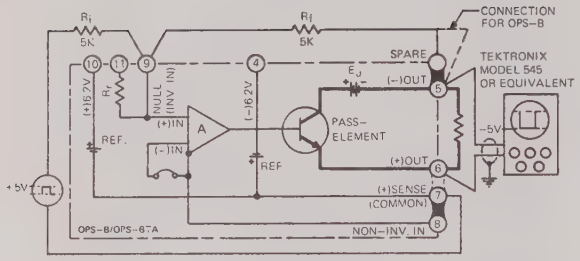


FIG. 3-4 TEST SET–UP

3-20 Turn OPS–B/OPS–BTA "on" and observe the resulting output wave form on a suitable oscilloscope (Tektronix Model 545 or equivalent). Adjust AC controls for optimum wave shape. (Refer to FIG. 3-5)

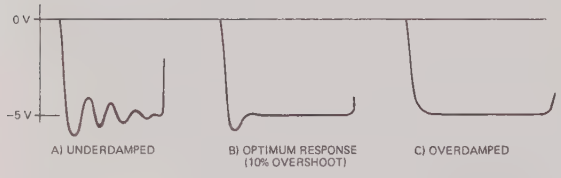


FIG. 3-5 SQUARE WAVE RESPONSE

3-21 SELECTION OF INPUT AND FEEDBACK RESISTORS

3-22 Selection of these components is generally based upon the desired operational gain and the characteristics of the input source. The following examples will illustrate the necessary calculations, the basis of which is the "ideal" transfer function (Eq.2)* for the operational power supply.

a) Example I: A Model OPS 21–2 BTA is to be programmed for a sine wave output of 20 volts peak to peak into a resistor load. The input source is a sine wave generator which can deliver 5 volts peak to peak into 600 ohms.

*NOTE: Refer to Section IV "THEORY OF OPERATION" for the derivation of this equation.

3-23 Since the OPS–BTA is a unipolar device, the input source must also either be unipolar (vary in one direction only) or, the DC output level of the amplifier must be pre-biased in such a way, that the amplified variations from a bi-polar source will be confined within its output range. (Refer to FIG. 3-6).

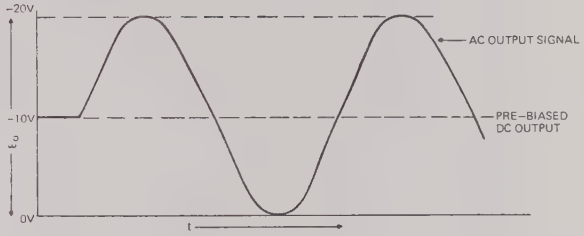


FIG. 3-6 PRE–BIASING TO ACCOMMODATE A BIPOLAR INPUT

3-24 In the above example, since we want an AC output swing from zero to 20 V peak and the input source is bipolar, we must adjust the DC output for (–) 10 volts at (mid-point) so that the amplified AC signal can swing around the (–) 10 volt axis. The output will also be unipolar, i.e. the 20 volt p-p wave form will have a (–) 10 V DC component. (See FIG. 3-6).

3-25 The desired DC level was established to be (–) 10 V. The input reference source (E_r) can deliver the necessary control current (I_b). If we apply the transfer function (Eq.2) to our DC conditions we have:

$$E_o = 10 \text{ V and } E_r = 6.2 \text{ V.}$$

From thermal stability considerations we select the control current to be 1 mA, so that:

$$I_b = \frac{E_r}{R_r} \text{ and } R_r = \frac{6.2V}{1mA} = 6.2K \text{ ohms.}$$

Since $I_b R_{vc} = E_o$, the 1 mA control current determines our feedback resistor,

$$R_{vc} = \frac{E_o}{I_b} \quad R_{vc} = \frac{10V}{1mA} = 10K \text{ ohms.}$$

R_r may be made adjustable to calibrate I_b to its exact value.

3-26 The AC output swing was established at 20 V p-p. The AC conditions are therefore as follows:

E_o = 20 V (p-p)

E_i = 5 V (p-p)

R_f = 10 K ohms (calculated previously)

It remains to calculate R_i using again equation (2):

$$R_i = \frac{5V\ (10K\Omega)}{20V} = 2.5K \text{ ohms.}$$

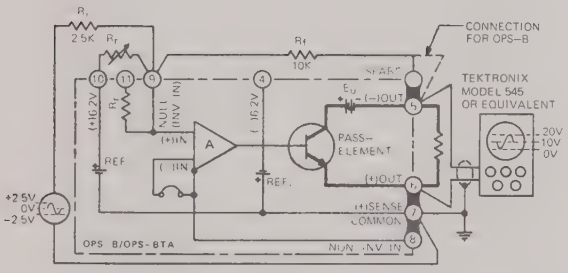


FIG. 3-7 SINE WAVE PROGRAMMING WITH PRE—BIASED OUTPUT

3-27 It is important for temperature stability and accuracy reasons that the selected components are quality, wire wound resistors with close tolerances. Portions of the selected input and reference resistors may be made variable if extreme accuracy is required. The complete programming set-up is now connected to the instrument as shown in FIG. 3-7 and operation can commence. From the frequency response chart (FIG. 1-3) it is seen that the OPS 21—1 BTA with a specified slewing rate of 500 KV/sec. has a maximum frequency response of 8 K Hz at 20 volts peak to peak. Beyond 8 K Hz, amplitude reduction and slope distortion will take place.

3-28 Example II: An OPS 100—0.2 BTA is to be programmed to produce a triangular wave with an amplitude of 100 volts. A Kepco Model FG 100 Function Generator is available to produce the input signal. This generator can produce an input current of 1 mA across 1000 ohms and can be connected for positive going input so that no DC pre-bias is necessary. The input and output wave forms and their phase relationship are illustrated in FIG. 3-8.

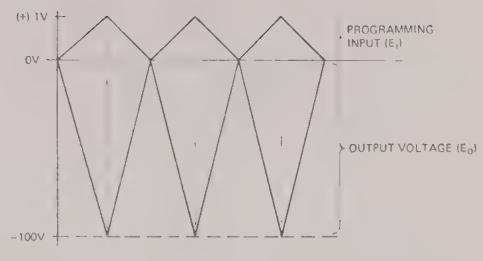


FIG. 3-8 PROGRAMMING WITH POSITIVE GOING INPUT SOURCE

3-29 Since the input source develops 1 volt at 1 mA, R_i = 1 V/1 mA = 1 K ohms. For 100 volt output, R_f is calculated to be:

$$R_f = \frac{E_o R_i}{E_i} = \frac{100V\ (1K)}{1V} = 100K \text{ ohms}$$

The programming set-up is now connected as shown in FIG. 3-9 and operation can commence.

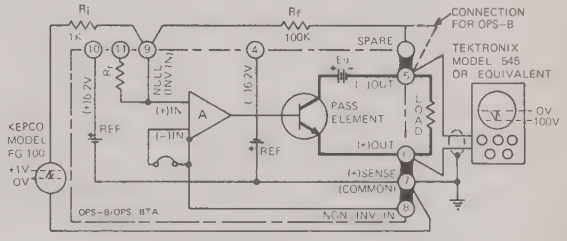


FIG. 3-9 PROGRAMMING WITH POSITIVE GOING SAWTOOTH WAVE

3-30 Example III: A 50 volt peak to peak square wave output is required from a OPS 72—0.3B. The available input source is a square wave generator with a negative output, but able to deliver at least 5 V at 1 mA of control current. Since in this case the input signal is of the "wrong" polarity, the OPS—TA will be DC biased to its maximum output voltage and, using this DC level as reference line, will be programmed "down" to the desired output voltage. Since either output on the OPS—B may be grounded, this programming arrangement has proven satisfactory in cases where the input polarity can not be changed readily. The input and output wave forms are illustrated in FIG. 3-10.

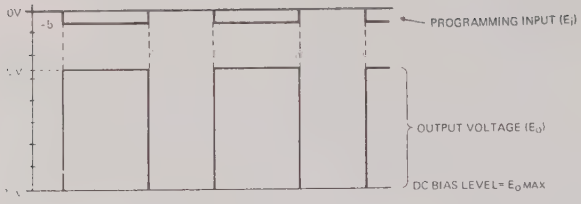


FIG. 3-10 BIASING FOR A NEGATIVE INPUT SOURCE

3-31 Component selection takes place as described previously:

DC conditions:

E_o = 72 volts

E_r = 6.2 V

I_b = 1 mA $\therefore R_r$ = 6.2K ohms

The feedback resistor is determined by the value of the control current (I_b = 1 mA) and found to be 72K ohms.

AC conditions:

E_o = 50 V (p-p)

E_i = 5 V (p-p)

R_f = 72K ohms

The required gain $\frac{E_o}{E_i}$ = 10, so that the ratio R_f/R_i must also equal 10, resulting in R_i =7.2K ohms.

This programming set-up is connected as shown in FIG. 3-11 and programming can commence. Monitor the output voltage across the load with a suitable oscilloscope. Overshoot and any other wave form distortions may be corrected by adjustments described in paragraph 3-17.

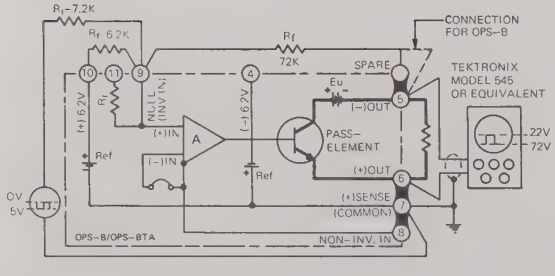


FIG. 3-11 SQUARE WAVE PROGRAMMING

3-32 OPS–B/OPS–BTA AS A CURRENT REGULATOR

3-33 The OPS–B/OPS–BTA can be set-up with external sensing and control resistors to provide regulated output current into any load within its maximum output current and compliance voltage range. The characteristics of a current regulator is such that his output voltage (compliance) changes proportional to the load resistance, thus maintaining the load current constant. Due to its low output capacity, the OPS exhibits excellent current recovery properties with rapidly changing loads. Its recovery time for a current step-function is directly related to its specified slewing rate. (See TABLE 1-1 for specified slewing rates on each model).

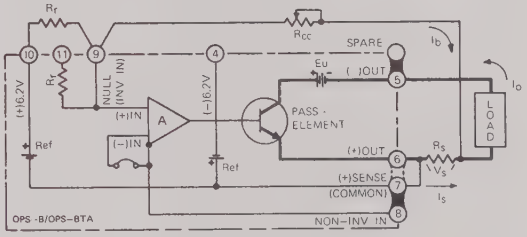


FIG. 3-12 OPS–B/OPS–BTA AS A CURRENT REGULATOR

3-34 Component selection will be shown by means of an example. An OPS 100–0.2 BTA is to be connected as a current regulator (Refer to FIG. 3-12) with the output current adjustable over its full range. If 1 volt of sensing voltage (V_S) is chosen across the sensing resistor (R_S) at I_O = 200 mA, the value of R_S is given by:

$$R_S = \frac{V_S}{I_O \text{ (max.)}} = \frac{1V}{0.2A} = 5 \text{ ohms.}$$

A wire wound resistor, at least 20 watt, with low temperature coefficient (20 ppm or better) should be chosen. The necessary control current I_b will be derived here from the internal reference source, although an external programming source could be selected as well. If we choose 1 mA for the control current value, a 6.2K ohm (wire-wound)

resistor is needed in series with the +6.2 V internal reference source,* (Refer to FIG. 3-12). R_{cc} the current control resistor, is now determined by making use of the balancing equation:

$$\frac{E_r}{R_r} = \frac{V_s}{R_{cc}} \quad \text{where } E_r/R_r = I_b = 1\text{mA} \quad \text{and } V_s = 1\text{V}$$

Substituting the selected values:

$$R_{cc} = \frac{1\text{V}}{1\text{mA}} = 1\text{K ohms.}$$

Connecting all components as shown in FIG. 3-12, the output current can be controlled (by varying R_{cc}) over nearly the full output current range from 200 mA down to 1 mA, which constitutes the minimum current because of the control current flowing in the opposite direction. The Kepco "Power Supply Handbook" lists several LOW CURRENT REGULATOR CIRCUITS for which this limitation does not apply.

*NOTE: The built-in reference resistor (R28) may be used in combination with a 1K ohm trim rheostat". The control current (I_b = 1 mA) can be thus accurately adjusted. Connect the rheostat between rear terminals (10) and (11).

3-35 OPERATION INTO CAPACITIVE LOADS

3-36 The Kepco Operational Power Supply/Amplifier is designed to drive non-reactive loads, but will tolerate capacitance up to 0.001 μF as specified. Oscillatory conditions which occur with loads up to this limit can usually be corrected by methods described in Paragraph 3-17 (Lag-Network Adjustments). If one desires to drive larger capacitive loads, several techniques can be employed, including the use of additional capacitance across the feedback terminals (5) and (9), alteration of the internal lag networks or isolation resistance in series with the load.

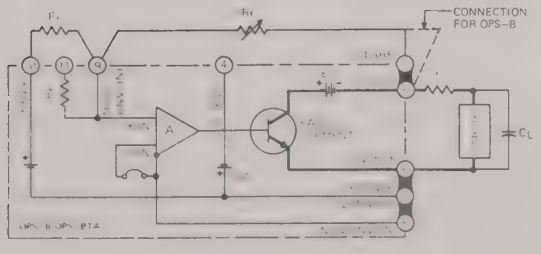


FIG. 3-13 SERIES RESISTOR EXTERNAL TO FEEDBACK LOOP

3-37 The latter method may be used in two variations:

a) Series Resistor external to feedback loop. The advantage of this method is that the network equations are not affected. The disadvantage of this method is the rise in output impedance, evidenced by degraded load regulation.

b) Series resistor inside the feedback loop. The advantage here is that load regulation is not affected. The disadvantage of this method is that the isolation resistor must be considered part of the feedback resistance R_f and enters the Operational Amplifier equation:

$$E_o = E_i \left(\frac{R_f + r'}{R_i}\right)$$

Also, the voltage drop across r' is of course lost and must be subtracted from the maximum output voltage of the OPS.

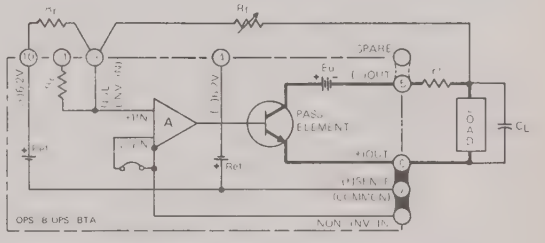


FIG. 3-14 SERIES RESISTOR PART OF FEEDBACK LOOP

3-38 The method suited for a particular load and the desired DC accuracy should be selected according to the importance of the relative advantages and disadvantages as described.

3-39 The best technique for assurance of stability consists of minimizing load capacitance as much as possible since ANY compensating method used has the disadvantage of narrowing the amplifiers bandwidth and reducing the slewing rate of the OPS Operational Power Supply.

3-40 REMOTE CURRENT LIMIT CONTROL

3-41 Internal turret terminals on the printed circuit board (See Main Schematic, FIG. 6-3 and Location Dwg. FIG. 6-2) have been provided on all OPS Models, permitting the disabling of the internal current limiting potentiometer and the (−)6.2 Reference Source for the external connection of a remotely located control. Remove jumper connections between turret terminals (E)-(F) and (H)-(G). Connect jumper between terminals

(E)-(G). The external components can now be connected as shown (Refer to FIG. 3-15) using shielded cable, and operation can commence.

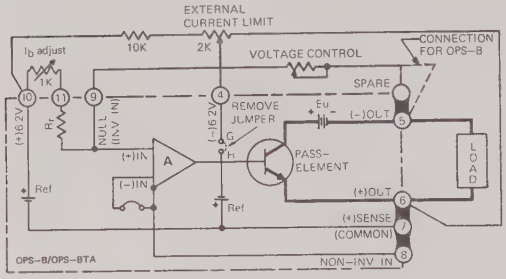


FIG. 3-15 CONNECTIONS FOR REMOTE CURRENT LIMIT CONTROL

3-42 PRACTICAL OPERATIONAL CIRCUITS

3-43 The following circuits represent a sample of other basic operational amplifier circuits, all of which have been found useful in practical applications and can be readily duplicated with the OPS–B/-OPS–BTA Operational Power Supply.

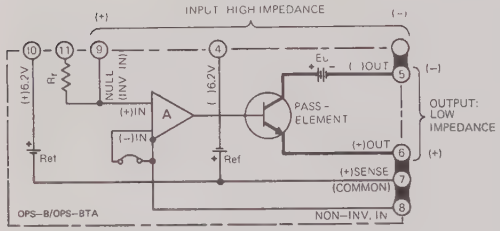


FIG. 3-16 IMPEDANCE TRANSFORMER (NON–INVERTING)

a) (FIG. 3-16) The OPS as an impedance transformer is connected as a unity-gain, non inverting amplifier. The input impedance will largely depend upon nulling of the offset current. (Refer to paragraph 3-10).

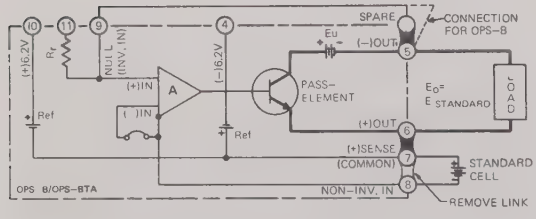


FIG. 3-17 STANDARD CELL REPEATER

b) (FIG. 3-17) A similar "impedance transformer" circuit is shown in a practical application as a standard cell repeater. In this circuit, the "non inverting" input of the operational power supply is used for the input to which the cell is connected. Load current may thus be drawn from the power supply which was not possible from the standard cell alone. Careful adjustment (I_{io} null) will reduce cell-loading to a few nano-amperes.

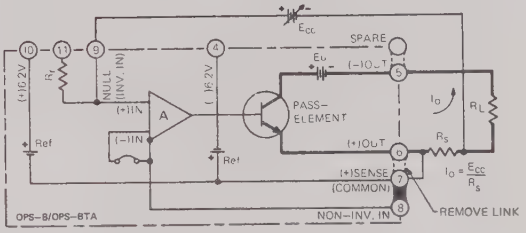


FIG. 3-18 CURRENT SOURCE, VOLTAGE CONTROLLED

c) (FIG. 3-18) Constant Current Source, adjustable by external control voltage. The output current (I_O) equals the ratio of the instantaneous control voltage (E_{CC}) to the value of the current sensing resistor (R_S).

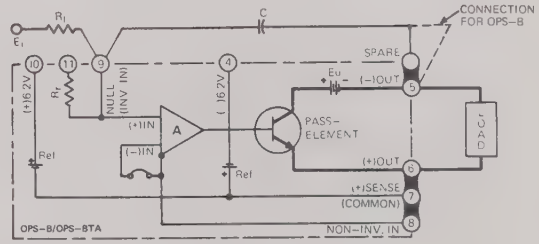


FIG. 3-19 INTEGRATOR

d) (FIG. 3-19) Integrator Circuit. Special attention must be given to the offset nulling procedures as described in paragraph 3-10. The integrating capacitor must be of very high quality (Mylar or Polystrene isulation) to prevent leakage.

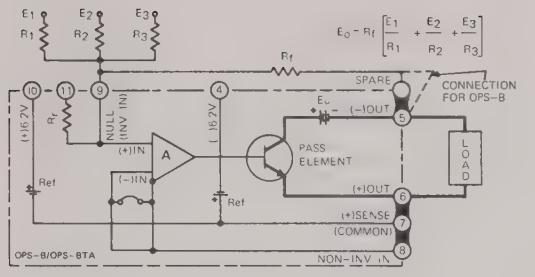


FIG. 3-20 SUMMING CIRCUIT

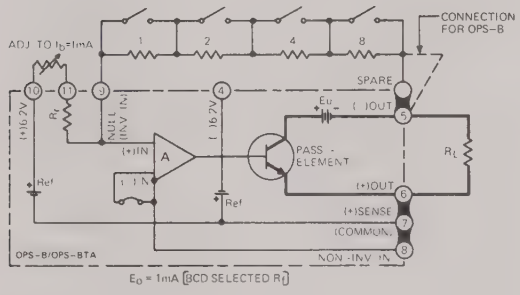


FIG. 3-21 DIGITAL PROGRAMMING

e) (FIG. 3-20) Summing Circuit.

$$\frac{E_1}{R_1} \quad \frac{E_2}{R_2} \text{ and } \frac{E_3}{R_3}$$

generate the control current in R_f without affecting each other, because the null junction decouples each from the other. The three currents:

$$\frac{E_1}{R_1} + \frac{E_2}{R_2} + \frac{E_3}{R_3}$$

passing through R_f, generate a voltage:

$$R_f \left[\frac{E_1}{R_1} + \frac{E_2}{R_2} + \frac{E_3}{R_3} \right]$$

which equals the output voltage E_o.

f) (FIG. 3-21) A computer controllable voltage source may be set up by digitally varying the feedback resistor (R_f) and providing the proper control current. The above example illustrates a BCD 1248 coded voltage control. The output voltage is given by:

E_o = 1 mA (BCD selected R_f)

SECTION IV – THEORY OF OPERATION

4-1 GENERAL

4-2 This section contains a description of the major circuitry of the OPS–B/OPS–BTA Operational Power Supply, proceeded by a simplified analysis of the operational concept. The discussion presented here should suffice for the purpose at hand: to provide the reader with the theoretial information for successful operation and maintenance of the instrument. Since the scope of this manual allows only for an abbreviated analysis, the reader is referred to the standard texts on operational amplifiers for a more extensive treatment.

4-3 OPERATIONAL POWER SUPPLIES

4-4 For many years, "Operational Amplifiers" have been used in the field of analog computing to perform various mathematical "operations". An operational amplifier is a high gain, DC coupled amplifier, stabilized externally by negative feedback to exhibit gain characteristics depending only on the external feedback components.

4-5 Since a regulated power supply contains such an amplifier in a closed loop configuration and in series with a power amplifier stage (consisting of the driver stage and the series regulator) it can be analyzed in terms of operational terminology. In fact, the power supply becomes a high power amplifier if the input terminals are made accessible. To complete the conversion, the bandwidth restricting output capacitor must be removed and the amplifier stabilized. The result is an "Operational Power Supply", programmable like an operational amplifier, with much higher power but single ended output.

4-6 THE IDEAL AMPLIFIER

4-7 For the purpose of analysis, an ideal model of the operational amplifier is proposed and the following assumptions are made:

a) The input terminal (null junction) will not conduct current to or from the amplifier.

b) The open loop gain is very large ($A \rightarrow \infty$).

c) The input voltage (ϵ) approaches zero when the feedback loop is closed ($\epsilon \rightarrow 0$).

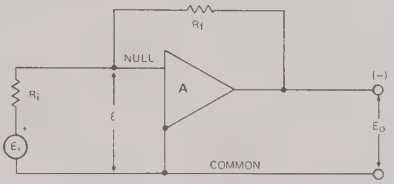
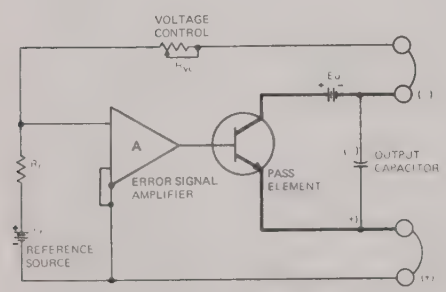


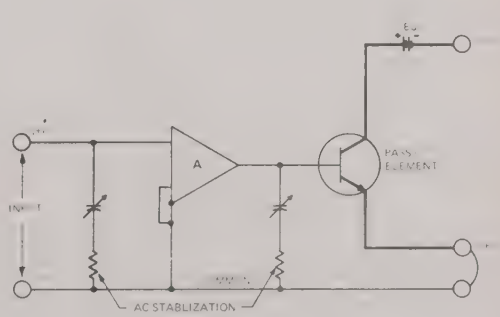
FIG. 4-2 MODEL OF IDEAL OPERATIONAL AMPLIFIER WITH FEEDBACK (INVERTING CONFIGURATION)

4-8 Refer to FIG. 4-2. Since (by the previous assumptions) the currents in R_f and R_i are equal, Kirchhoffs' loop equation may be written as:

$$\frac{E_i - \epsilon}{R_i} + \frac{E_o + \epsilon}{R_f} = 0 \quad \text{(Eq. 1)}$$



a) POWER SUPPLY



b) OPERATIONAL POWER SUPPLY/AMPLIFIER

FIG. 4-1 POWER SUPPLY–AMPLIFIER CONVERSION

By definition, $E_o = -A\epsilon$, where A represents the open loop gain.

$$\text{also } \epsilon = \frac{E_o}{A}$$

If we let $A \rightarrow \infty, \epsilon \rightarrow 0$ then (Eq. 1) becomes

$$\frac{E_i}{R_i} + \frac{E_o}{R_f} = 0;$$

or in the more familiar form,

$$E_o = -E_i \frac{R_f}{R_i} \text{ (Eq. 2), where } \frac{R_f}{R_i}$$

represents the closed loop gain (G).

4-9 THE PRACTICAL AMPLFIIER

4-10 The closed loop relationships derived for the ideal model of the operational amplifier, may be applied to the practical case with very small predictable errors which in addition can be compensated for. The "ideal" amplifier equation (2) for example may be used to calculate the magnitude of the feedback and input components with negligible errors which will be well within the component tolerances. In evaluating the DC performance however, these errors can not be neglected.

4-11 AMPLIFIER OFFSETS. In developing the ideal amplifier model, we tacitly assumed the null junction voltage and current to be zero, causing the "ideal" equation (2) to be valid. In reality however, nonidealities do exist at the null junction or input terminal of the amplifier. These errors are of the form of an offset voltage (E_{io}) and an offset current (I_{io}). The modified version of the amplifier model can be shown with these error sources as in FIG. 4-3:

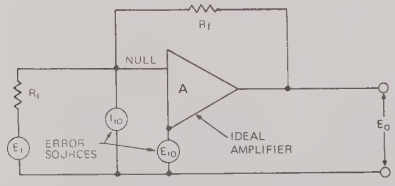


FIG. 4-3 AMPLIFIER WITH INPUT OFFSET SOURCES

4-12 Although both offsets may initially be zeroed (by compensating sources with opposite polarities, as in the OPS–B/OPS–BTA power supplies) their VARIATION from zero under the influence of the AC line, DC load, temperature and time produce an error voltage (ΔE_o) at the output. The magnitude of the error voltage depends entirely upon the operational gain and the feedback components chosen by the user. It is for this reason that the input offset are specified as "ΔE_{io}" and "ΔI_{io}" at the null junction of the operational power supply (Refer to TABLE 1-2).

4-13 Considering both offset variations, the modified expression for output voltage (with the initial or fixed parts of E_{io} and I_{io} nulled) becomes:

$$E_o = \underbrace{E_i \frac{R_f}{R_i}}_{\text{"IDEAL" Part of } E_o} + \underbrace{\Delta E_{io}\left[\frac{R_r}{R_i} + 1\right]}_{\text{Output effect of an offset voltage change}} + \underbrace{\Delta I_{io} R_f}_{\text{Output effect of an offset current change}} \text{ (Eq. 3)}$$

As seen from equation (3), the offset voltage variations (ΔE_{io}) are multiplied by one, plus the gain ratio (R_f/R_i) to obtain its contribution to the output voltage change, while the offset current variations are multiplied by the value of the feedback resistor (R_f). The separation of the specifications for ΔE_{io} and ΔI_{io} not only allows an analysis of the contributions form each offset variation, but also permits component selection such as to minimize the effects of either offsets or find an acceptable compromise.

4-14 A practical example will illustrate that input and feedback resistors should not be chosen arbitrarily:

a) For an application calling for unity gain, a programming circuit is to be set-up with a Model OPS–B/OPS–BTA. From the table of specifications the offsets vary with line voltage as follows:

$\Delta E_{io} = 10\,\mu V$

$\Delta I_{io} = 2\,nA$

If we chose R_i indiscriminantly to be for example 200K ohms, then for R_f/R_i = unity gain, R_f = 200K. Consequently the expected output variations vs. line changes are (from Eq.3):

$$\Delta E_o = \Delta E_{io}\frac{R_f}{R_i} + 1 + \Delta I_{io}R_f$$

$$= 10\,\mu V\,(1+1) + 2nA\,(200K)$$

$$\underbrace{= 20\,\mu V}_{\Delta E_o \text{ due to } \Delta E_{io}} \qquad \underbrace{+ 400\,\mu V}_{\Delta E_o \text{ due to } \Delta I_{io}}$$

The contribution of ΔI_{io} are seen to be twenty times that of ΔE_{io}, due of course, to the selection of a relatively large value feedback resistor. Generally therefore, it is advisable to select lower values of R_f in low gain applications, if the loading on the

input source will permit it. If for example we would have selected $R_i = R_f = 10K$ ohms, the total output variation (ΔE_o) would only be $20\,\mu V + 20\,\mu V = 40\,\mu V$, each offset contributing an equal share to the output voltage error.

b) In applications where high operational gain is required, the contirbution of ΔE_{io} will be dominant, as seen by calculating the output variations for and R_f/R_i ratio of 100: Selecting R_i to be 1K ohm, R_f = 100K ohm ($R_f/R_i = 100$), the output variations for the specified AC line changes are:

$$\Sigma\Delta E_o = \underbrace{10\,\mu V\,(100+1)}_{=1010\,\mu V} + \underbrace{2 \times 10^{-9} A\,(1 \times 10^5 \text{ ohms})}_{+20\,\mu V}$$

ΔE_o due to ΔE_{io} $\quad$ ΔE_o due to ΔI_{io}

In these cases of large gain ratios the output effects caused by ΔE_{io} can only be reduced by externally limiting wide variations of the AC line voltage.

4-15 By inserting the appropiate specification into the given equation (Eq.3), output variations due to load changes, temperature variations or stability (changes of E_o with time) may be predicted. Consideration must be given to variations of the external feedback and input components when performing these calculations.

4-16 CIRCUIT DESCRIPTION (Refer to Main Schematic, FIG. 6-3)

4-17 For the purpose of convenient analysis, the circuitry of the OPS–B/OPS–BTA operational power supplies may be divided into several sections, which are subsequently described below:

a) AC INPUT CIRCUIT. AC line power is introduced through the rear printed circuit board (PCB) connector (P1), terminals (1) and (2). Terminal (3) is connected to the chassis and should always be returned to AC ground. Once the front panel slide switch/indicator is closed,* primary power is applied to the main transformer (T201) and the indicator lamp.* T201 has two primary windings, which are either connected in parallel (for 115V AC service) or in series (for 230V AC service). The fuse (F1) protects the primary winding of T201 from excessive current.

b) MAIN DC POWER SUPPLY. The main DC power is derived from a secondary winding on the main transformer (T201). Rectification and filtering is performed by a conventional bridge-rectifier circuit (CR4 to 7) and an electrolytic capacitor (C3). The main DC power supply delivers the rated output current and the operating voltage for the pass transistor.

c) PASS TRANSISTOR CIRCUITRY. The pass transistor (Q201,202) is connected in series with the plus (+) output terminal, the current sensing resistor (R14), the external load and the (unregulated) main DC supply. The output current flowing in this series loop is kept constant, regardless of external changes in load resistance or AC input voltage, since the effective series resistance of the pass transistor is altered in reference to these changes. The base drive needed to produce this corrective action by the pass transistors is supplied by the driver stage (Q2), which in turn is driven by either the Error Signal Amplifier (A_V), or the current limit amplifier (Q3,4).

d) ERROR SIGNAL AMPLIFIER (A_V). This device is a DC coupled, high-gain operational feedback amplifier, especially designed for operational power supply duty. Both inputs are available at the rear, with the non-inverting input normally connected to the "common". The function of the amplifier is to amplify input signals to a level suitable to pass the gate circuit (CR16,17) and drive the power transistors in the pass-element section.

e) CURRENT LIMIT CIRCUITRY. The current limiting circuitry has the function to prevent output current flow beyond the maximum rated value. It performs this function by "cutting off" the pass transistor as soon as this value is reached. The differential inputs of the current limit amplifier (A_I = Q3,4) are connected to a current sensing resistor R_S (R14) and (via R25) to a reference voltage. The voltage drop across R_S (due to load current flow) is continuously compared to the pre-set voltage at the "I_O Limit" control (R15).* As long as the voltage developed across R_S is less than the pre-set voltage level at R15,* the current amplifier will be biased to its inactive state and will have no effect on the output. Both, the current limit amplifier and error signal amplifier (A_V) are coupled through their respective gate diodes (CR16,17) to the driver transistor (Q2). The amplifier with the larger (negative) output will control the pass elements while the other amplifier is de-coupled.

*AC Switch/Indicator (SDS101) on OPS–BTA Models Only.

*R301 in OPS–BTA Models.

Since the voltage drop across the sensing resistor is proportional to the output current, and the "I_O limit" may be set to a voltage proportional to the desired output current, the current amplifier is inactive as long as the output current does not exceed the pre-set level. If the output current does increase however, the current amplifier will produce an output signal more negative than A_V, thereby taking control away from the voltage amplifier A_V and limiting the output current sharply in the process.

f) AUXILIARY SUPPLIES

1) AMPLIFIER POWER SUPPLY. This full wave, capacitor filtered source consists of a center-tapped winding on T201, silicon rectifier CR1,CR2 and the filter capacitor C1. A current regulator stage (Q1) followed by a string of zener diodes (CR11,CR12,CR13,CR14) provides the operating voltages for the amplifiers and is the source of the temperature compensated reference voltages (CR18,CR19). The positive reference voltage serves as the comparison source for the error signal amplifier (A_V) and produces the control current if the OPS–B/-OPS–BTA is used in the power supply mode. In the amplifier modes, the reference sources can be used for biasing or level shifting purposes. The DC offset control (E_{io} Null, R21)* is derived from the positive side of the amplifier power supply. The offset control allows for precision zeroing of the initial amplifier offset.

2) DRIVER COLLECTOR SUPPLY: A half-wave, capacitor filtered supply is derived from a winding on T201, rectified by silicon diode CR3 and filtered by C2. It delivers collector voltage to the driver transistor (Q2). R6 is a bleeder and CR15 is the coupling diode to the pass transistor.

3) I_{cbo} SUPPLY: The operating voltages for the I_{cbo} circuitry are derived from the main power supply. Q5 is biased by the voltage drop across the series diodes (CR9,10) in such a way as to draw a relatively constant current, thus providing a current sink for the I_{cbo} of the pass elements. This ensures positive cut-off, especially at high operating temperatures.

*R302 in OPS–BTA Models.

SECTION V – MAINTENANCE

5-1 GENERAL

5-2 This section contains maintenance and calibration procedures for the Kepco OPS–B/OPS–BTA Operational Power Supply as far as these procedures have not been covered in previous sections. Conservative rating of all components and avoidance of congested lay-out should keep maintenance to a minimum. If component failure should take place however, the ease of disassembly in conjunction with complete component lay-out drawings, electrical schematics and information contained in this and the previous section will help to keep the "down time" of this equipment to a minimum.

5-3 OUTPUT CURRENT LIMIT CONTROL CALIBRATION

5-4 A single turn control ("I LIMIT", refer to FIG. 5-2 for location) serves as an adjustment for limiting the output current through the range from approximately 10% to 110% of the rated maximum output current. Although an adjustment beyond 110% may be possible due to component tolerances, great care should be taken that this limit is not exceeded. Overheating and subsequent destruction of components may result.

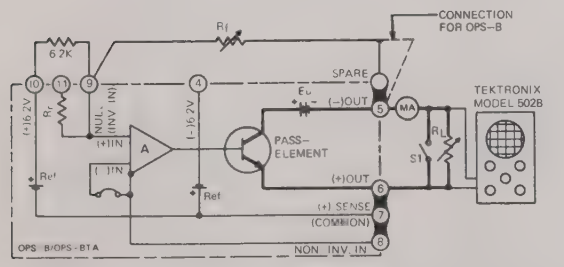


FIG. 5-1 CONNECTIONS FOR CURRENT LIMIT CALIBRATION

5-5 PROCEDURE, CURRENT LIMIT CALIBRATION

a) Connect test set-up as shown in FIG. 5-1.

b) Turn the OPS on, and adjust R_f to the desired output voltage. Adjust load resistor R_L to draw the desired output current, plus approximately 5% of I_O maximum rated.

c) Locate the "I LIMIT" control (See FIG. 5-2) and adjust slowly until the output ripple, as observed on the oscilloscope, increases. Back off slightly on the control until the ripple appears normal again.

d) Close S-1. The short circuit current as read out on ammeter M-1, will be approximately equal to the adjusted load current, plus 5 mA.

5-6 TROUBLE SHOOTING

5-7 The repair of precision power supplies and operational amplifiers requires a thorough understanding of the problem involved as well as experience with solid state circuitry and closed loop systems. "Trouble Shooting Charts", which give resistance and voltage readings in various places in this circuitry are of little value in feedback amplifiers and are for this reason not included here. Presented instead are:

a) An extensive operational theory. (Section IV)

b) A circuit description. (Section IV)

c) Detailed diagrams showing adjustment and parts location. (Section V).

d) Main Schematic showing the complete circuitry of the OPS Operational Power Supply and a complete parts list. (Section - VI)

5-8 It has been found in our experience, that in many cases of malfunctioning, the trouble can be traced to external causes. It is suggested that if trouble is encountered, the OPS is set-up as an operational power supply as shown in FIG. 5-1, but without a load. After the test set-up is completed, check the following points:

a) NO OUTPUT. Check AC input line for correct line voltage. Check fuse (See FIG. 5-2 for location). Compare carefully the terminal numbers of the circuit symbols as given in FIG. 2-1.

b) HIGH OUTPUT. Check correct ratio of R_f/R_i. Make certain both input and feedback resistors are connected to their proper terminals. Test transistors. Check reference voltage (nominal 6.2 volts).

5-9 If the OPS works well as a power supply as described in Paragraph 5-8, and trouble is encountered under programming with a square-wave generator, or oscillation persists, the

lag-network settings should be checked and readjusted if discrepancies between input signal and output voltage are observed. (Refer to paragraph 3-17). If oscillations are observed at the output and resetting of the lag network will not correct it, an adjustable trimmer capacitor (C_f) is provided across the feedback terminals. Adjust for critical damping. Although the response time or slewing rate will suffer somewhat, in many cases this compromise may be helpful.

5-10 The main schematic (FIG. 6-3) shows the voltage readings for all reference voltages and the more important operating voltages for the OPS as measured with the unit as a power supply. These values are nominal and may differ from the noted values approximately ±10%.

5-11 It is hoped that this material will provide the necessary information in case of malfunction. Kepco Field Engineering Offices and the Kepco Repair Department are always available for prompt service in difficult cases.

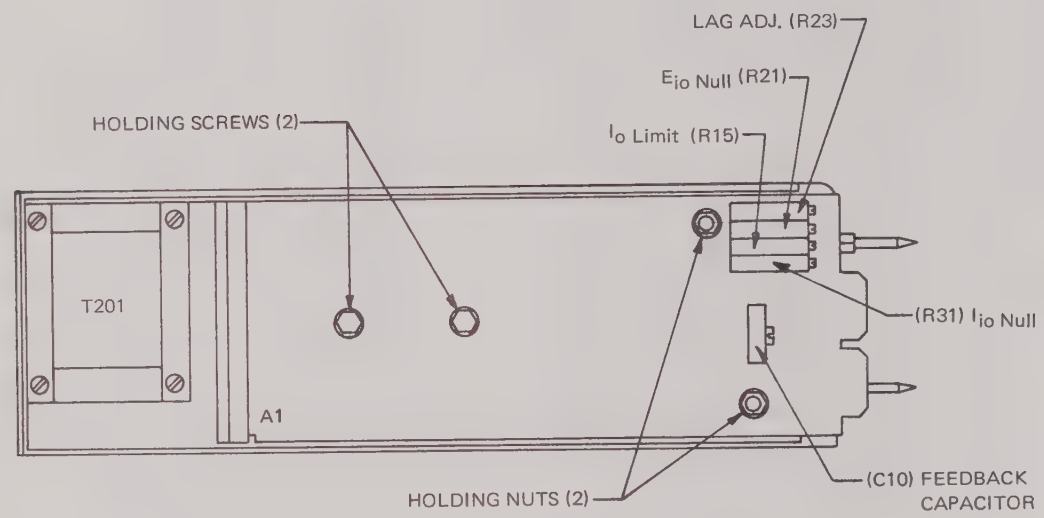


FIG. 5-2 LOCATION OF INTERNAL ADJUSTMENTS AND MOUNTING SCREWS, OPS–B MODELS (MAIN CHASSIS ASSEMBLY, A2)

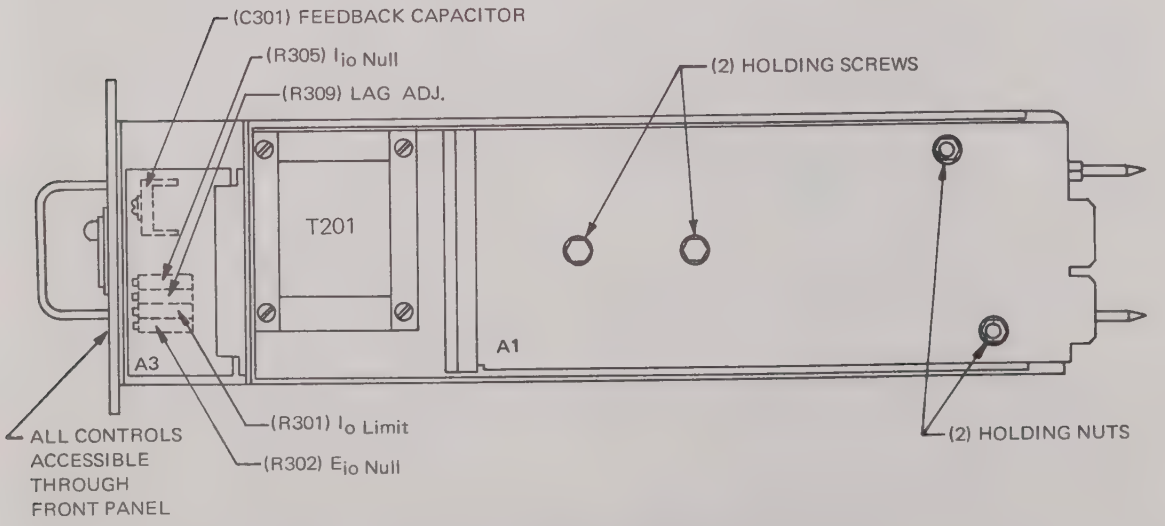


FIG. 5-3 LOCATION OF INTERNAL ADJUSTMENTS, AND MOUNTING SCREWS, OPS–BTA MODELS (MAIN CHASSIS ASSEMBLY, A2)

5-12 TEST MEASUREMENTS

5-13 Test measurements to verify the specifications of the operational power supply are frequently a requirement for "Incomming Inspection", or are a part of a regular maintenance procedure. Adequate test facilities and equipment, as well as great care in the performance of these measurements are of prime importance if valid results are exprected. Since many performance measurements on operational power supplies and amplifiers require specialized test equipment and rigidly controlled environment conditions, only such tests are described which may be performed with conventional equipment in a standard environment (Refer to paragraph 5-14).

5-14 TEST EQUIPMENT REQUIRED

5-15 The following is a listing of the test equipment required to measure some important parameters on the Kepco OPS–B/OPS–BTA Operational Power Supplies.

a) Line Step Device or variable transformer capable of adjusting the power line from 105V to 125V AC and rated to deliver the maximum input current for the instrument under test. (T1).

b) DC Null Indicator. Differential or digital voltmeter with a resolution of at least 5 μV/1 nA; KEITHLEY Model 150B or HP Model 419A or equivalent.

c) RMS reading voltmeter for ripple monitoring, Ballantine Model 320A or equivalent.

d) Oscilloscope for output ripple observance Tektronix, Model 502B or equivalent. (Optional)

e) Multimeter for measuring pass element voltage and general trouble shooting measurements. 20K ohm/V, Weston Analyzer Model 980 or equivalent.

f) Precision DC ampere meter with a range covering the maximum output current of the Model under test. (Weston Model 931 or equivalent).

g) Oscilloscope for AC performance measurements. Tektronix, Model 545 or equivalent.

5-16 DC MEASUREMENTS

5-17 Variations of the offset voltage (ΔE_{io}) and offset current (ΔI_{io}) with AC line changes are an excellent indication of the regulation (short-time stability) of the operational power supply. The specifications for these parameters are given in Section I and may be readily verified by following the instructions and diagrams below:

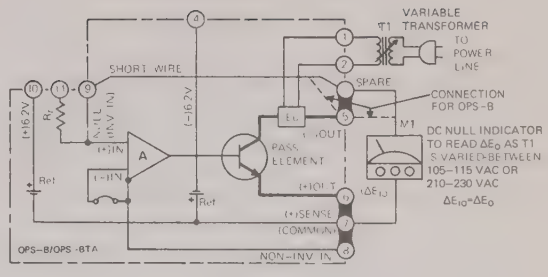


FIG. 5-4 DC TEST MEASUREMENTS (ΔE_{IO})

a) Variations in offset voltage (ΔE_{io}). Measurements are made with the circuit shown in FIG. 5-4. Since the feedback terminals are shorted out ($R_f = 1$), and the input is disconnected, the operational gain is unity. Whatever offset voltage exists between null junction and common will be transfered directly to the output. Monitoring the output by means of a sensitive null detector while varying the AC line input (or temperature, or time if facilities permit) will allow measurement of ΔE_{io} at the output.

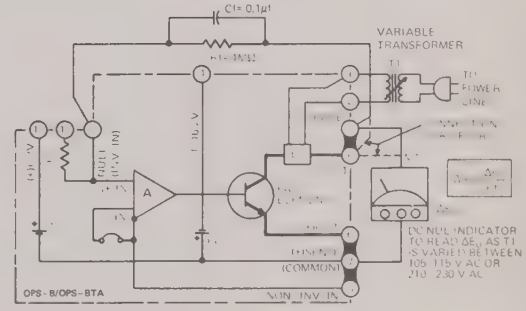


FIG. 5-5 DC TEST MEASUREMENTS (ΔI_{io})

b) Variations in Offset Current (ΔI_{io}). Measurements are made with the circuit shown in FIG. 5-5. Since the offset current will have to flow through the feedback resistor it produces an output voltage E_o which is equal to $I_{io}R_f$. Monitoring the output voltage by means of a sensitive DC nullmeter, while varying the AC line input (or temperature, or time if facilities permit) will yield an indication of ΔI_{io} when the output voltage is divided by the value of the feedback resistor.

$$(\Delta I_{io} = E_o/R_f)$$

5-18 AC MEASUREMENTS.

5-19 The slewing rate or programming speed of the OPS–B/OPS–BTA may be verified by measuring the rise and fall time at the output when the instrument is programmed with a square wave in a low gain configuration (worst case). FIG. 5-6 shows the necessary test set-up. The specified slewing rate is calculated by measuring the fall time (worst case) of the output wave form and converting the results to "volt per micro-second". And overshoot or other distortion encountered may be corrected by adjusting the AC stability as described in paragraph 3-17.

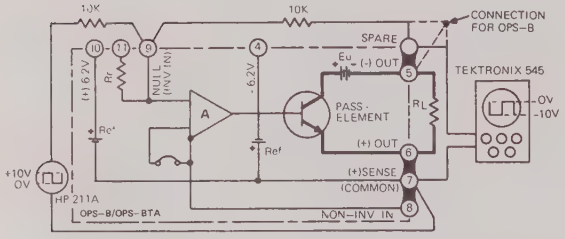


FIG. 5-6 AC TEST MEASUREMENTS (SLEWING RATE)

5-20 As shown in FIG. 5-7 below, the "fall-time" (t_f) is measured from the peak output (–10V) to the 63% point (one time constant). The slewing rate is then defined as:

$$\text{Slewing Rate} = \frac{63\%\ E_O\ \text{(peak to peak)}}{t_f}$$

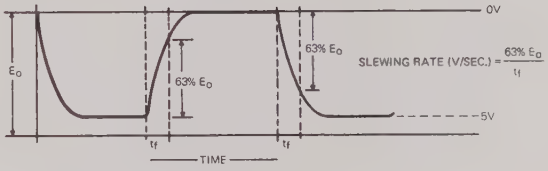


FIG. 5-7 OUTPUT WAVE FORM FOR SLEWING RATE MEASUREMENTS

SECTION VI – ELECTRICAL PARTS LIST AND DIAGRAMS

6-1 GENERAL

6-2 This section contains the main schematic, the parts location diagrams, and a list of all replaceable electrical parts. All components are listed in alpha-numerical order of their reference designations. Consult your Kepco Representative for replacement of parts not listed here.

6-3 ORDERING INFORMATION

6-4 To order a replacement part or to inquire about parts not listed in the parts list, address order or inquiry either to your authorized Kepco Sales Representative or to:

KEPCO, INC.
131–38 Sanford Avenue
Flushing, N.Y. 11352

6-5 Specify the following information for each part:

a) Model and complete serial number of instrument.

b) Kepco part number.

c) Circuit reference designator.

d) Description.

6-6 To order a part not listed in the parts list, give a complete description and include its function and location.

PRINTED CIRCUIT BOARD ASSEMBLY (A1), MODEL OPS 72–0.3B **Code 5-1669**

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
A_V	1	Plug-In Amplifier	Fairchild ADO-49	250-0013
C1	1	Capacitor,Electrolytic,Pigtail 75 μF, 50 V	Sprague 30D756G050DF2	117-0646
C2	1	Capacitor,Electrolytic,Pigtail 290 μF, 12 V	Sprague 30D297G012DF2	117-0647
C3	1	Capacitor,Electrolytic,Pigtail 310 μF, 150 V	Sprague 38D317F150HS4	117-0680
C4	1	Capacitor,Ceramic,Disc. 5000 pF, 500 V, 20%	Radio Materials Type SM	117-0061
C7	1	Capacitor,Mylar,Pigtail 1.0 μF, 200 V, 10%	Wesco 33MM	117-0207
C8	1	Capacitor,Electrolytic,Pigtail 150 μF, 3 V	General Electric 76F02BF151	117-0512
C9	1	Capacitor,Mylar,Pigtail 0.001 μF, 200 V, 10%	Sprague 192P10292	117-0570
C10	1	Capacitor,Variable 170 – 780 pF, 175 – 350 V	Arco PC46	117-0594
C11,12, 13,14	4	Capacitor,Mylar,Pigtail 0.01 μF, 400 V, 10%	Sprague 192P10304	117-0361
CR1,2,3,9, 10,15,16,17	8	Rectifier,Silicon,Pigtail	Semicon SM110	124-0133
CR4,5,6,7, 20,22	6	Rectifier,Silicon,Pigtail	Semtech SE-4	124-0028
CR8,11,12, 13,14	5	Zener Diode	Transitron 1N763-1	121-0028
CR18,19	2	Zener Diode	International Rectifier 1N821	121-0041
CR21	1	Rectifier,Silicon,Pigtail	Solitron 124-0178	124-0178
F1	1	Fuse, Slow Blow 0.8 A	Bussman MDL 8/10	141-0027
Q1,2,3,4	4	Transistor,Silicon,NPN	M.S. Transistor 119-0056	119-0056
Q5	1	Transistor,Silicon,NPN	M.S. Transistor MST20	119-0079
R1	1	Resistor,Fixed,Precision,M.F. 232 ohm, 1/4 W, 1%	IRC CEA Type	115-2310
R2	1	Resistor,Fixed,M.G. 82 K ohm, 1/4 W, 5%	IRC RG 1/4	115-2012
R3	1	Resistor,Fixed,Molded 3.9 K ohm, 1/2 W, 10%	Allen Bradley EB3921	115-0921
R4	1	Resistor,Fixed,Molded 1 K ohm, 1/2 W, 5%	Allen Bradley EB1025	115-0340
R5	1	Resistor,Fixed,Molded 560 ohm, 1/2 W, 10%	Allen Bradley EB5611	115-0451
R6	1	Resistor,Fixed,M.G. 82 ohm, 1/4 W, 5%	IRC RG 1/4	115-2308

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

PRINTED CIRCUIT BOARD ASSEMBLY (A1), MODEL OPS 72–0.3B Code 5-1669

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
R7	1	Resistor,Fixed,Power,Axial 5.0 K ohm, 3 W, 5%	Tepro TS-30	115-1094
R8	1	Resistor,Fixed,Precision,M.F. 20 K ohm, 1 W, 1%	IRC CEC Type	115-2039
R10	1	Resistor,Fixed,Molded 390 ohm, 1/4 W, 10%	IRC GBT 1/4	115-2234
R11	1	Resistor,Fixed,Power,Axial 10 K ohm, 3 W, 5%	Hardwick Hindle 9/16 GA46-10K	115-0460
R12	1	Resistor,Fixed,Molded 47 K ohm, 1/4 W, 10%	IRC GBT 1/4	115-2237
R13	1	Resistor,Fixed,M.G. 6.2 K ohm, 1/4 W, 5%	IRC RG 1/4	115-2258
R14	1	Resistor,Fixed,Power,Axial 1.667 ohm, 3 W, 3%	Tepro TS3W	115-1872
R15	1	Resistor,Variable,Cermet 2 K ohm, 3/4 W, 20%	Beckman 78PR2K	115-2032
R16	1	Resistor,Fixed,Molded 10 K ohm, 1/4 W, 10%	IRC GBT 1/4	115-2211
R21,31	2	Resistor,Variable,Cermet 50 K ohm, 3/4 W, 20%	Beckman 78PR50K	115-2104
R22,24	2	Resistor,Fixed,Precision,M.F. 750 ohm, 1/4 W, 1%	IRC CEA Type	115-2259
R23	1	Resistor,Variable,Cermet 200 ohm, 3/4 W, 20%	Beckman 78PR200	115-1996
R25	1	Resistor,Fixed,Precision,M.F. 10 K ohm, 1/4 W, 1%	IRC CEA Type	115-2174
R26	1	Resistor,Fixed,Precision,M.F. 2 Meg ohm, 1 W, 1%	IRC CEC Type	115-2100
R28	1	Resistor,Fixed,Precision,M.F. 5.76 K ohm, 1/4 W, 1%	IRC CEA Type	115-2222
R30	1	Resistor,Fixed,Molded 560 ohm, 1/4 W, 10%	IRC GBT 1/4	115-2210
R32	1	Resistor,Fixed,Molded 2 K ohm, 1/2 W, 5%	Allen Bradley EB2025	115-0520
R33	1	Resistor,Fixed,Precision,M.F. 210 ohm, 1/4 W, 1%	IRC CEA Type	115-2177

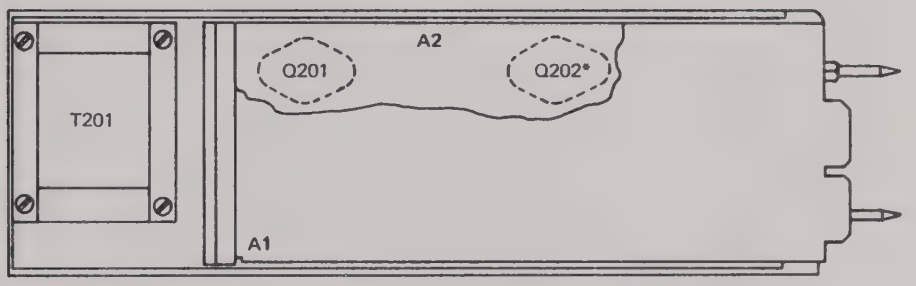
MAIN CHASSIS ASSEMBLY (A2), MODEL OPS 72–0.3B

Q201	1	Transistor,Silicon,NPN	RCA 2N3442	119-0070
T201	1	Transformer	Kepco Magnetics	100-1771

NOTE:

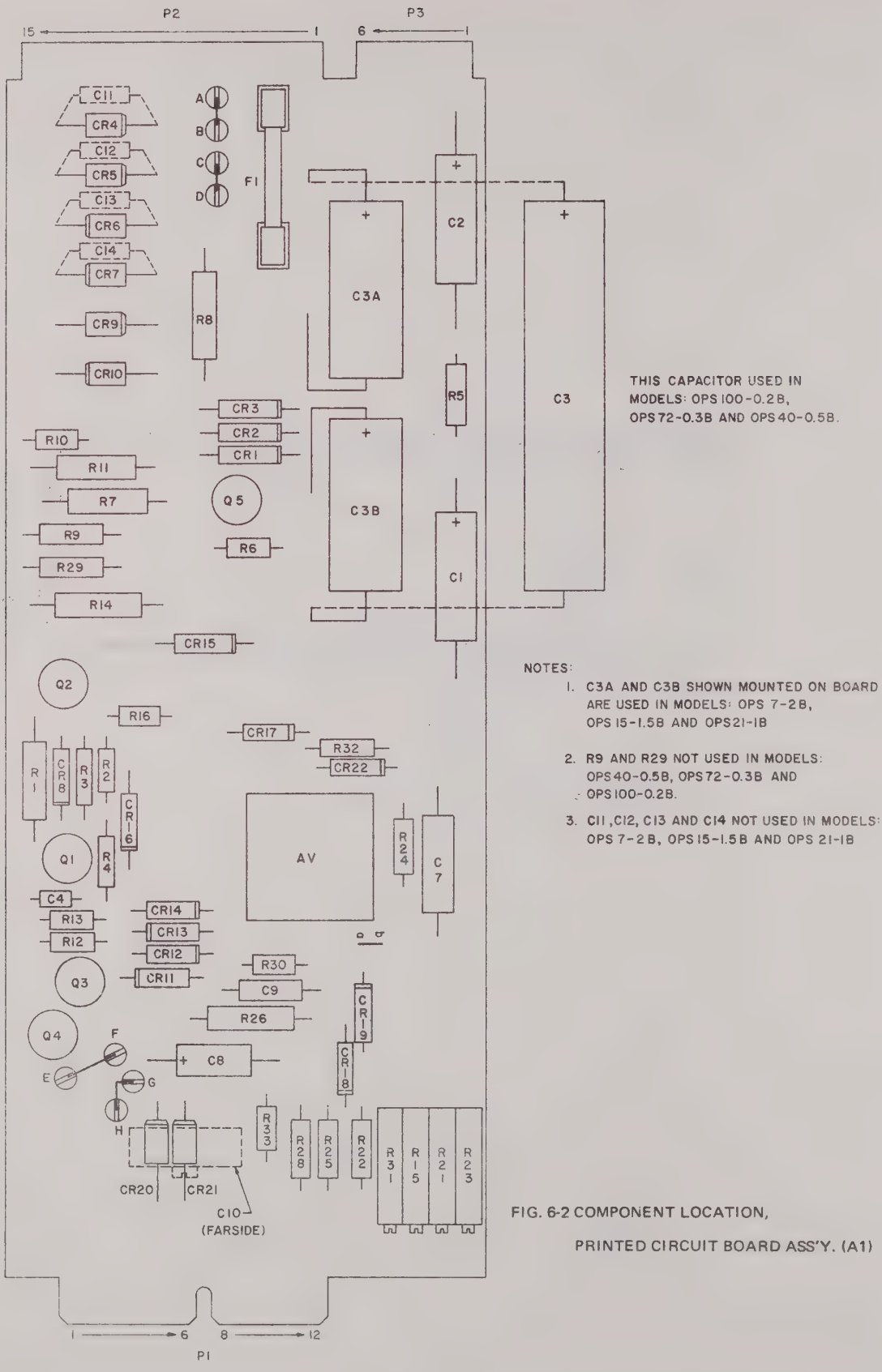
REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.



*NOT USED IN MODELS OPS 40–0.5B
OPS 72–0.3B
OPS 100–0.2B

FIG. 6–1 COMPONENT LOCATION, MAIN CHASSIS



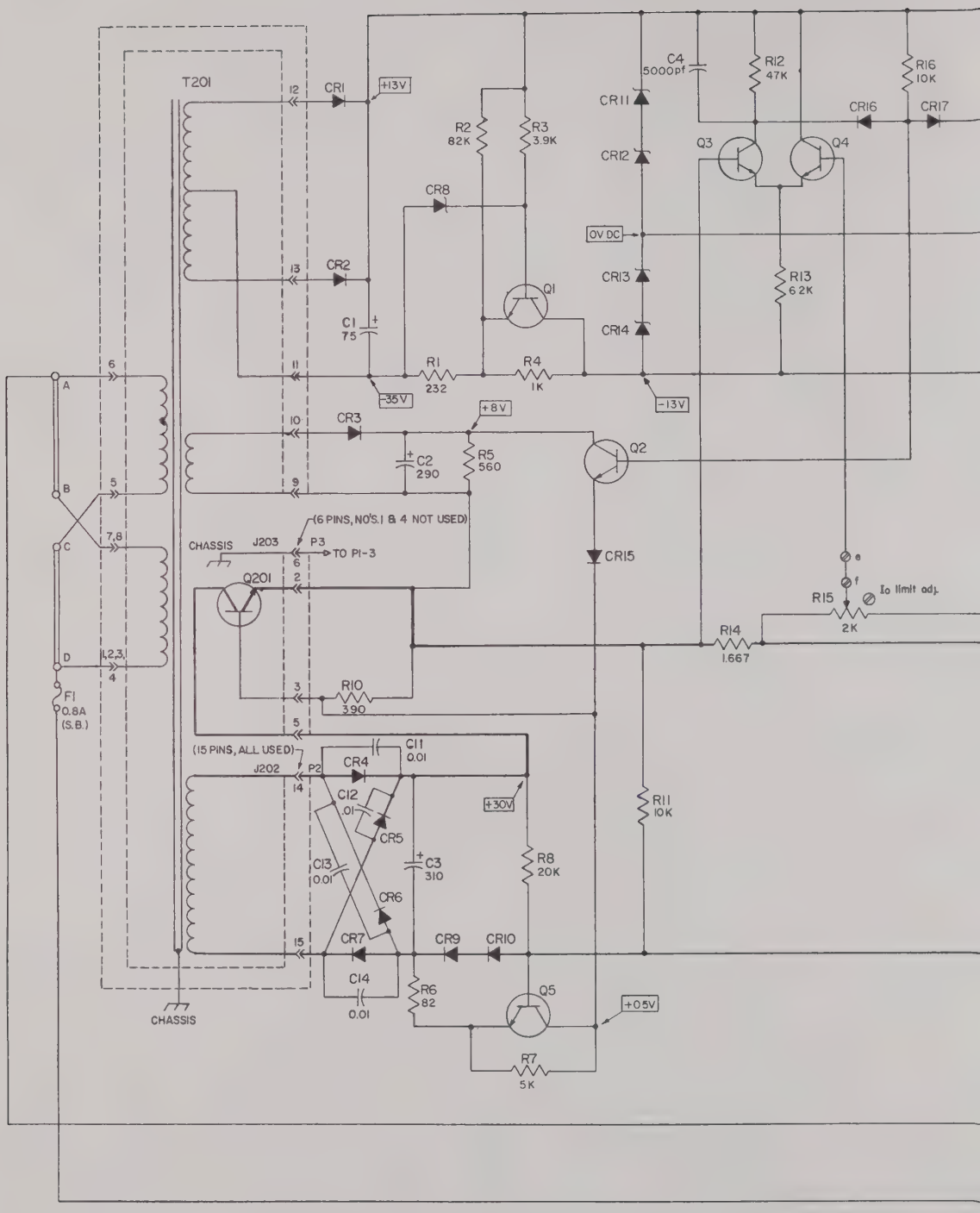
THIS CAPACITOR USED IN MODELS: OPS 100-0.2B, OPS72-0.3B AND OPS40-0.5B.

NOTES:

1. C3A AND C3B SHOWN MOUNTED ON BOARD ARE USED IN MODELS: OPS 7-2B, OPS 15-1.5B AND OPS21-1B
2. R9 AND R29 NOT USED IN MODELS: OPS40-0.5B, OPS72-0.3B AND OPS100-0.2B.
3. C11, C12, C13 AND C14 NOT USED IN MODELS: OPS 7-2B, OPS 15-1.5B AND OPS 21-1B

FIG. 6-2 COMPONENT LOCATION,

PRINTED CIRCUIT BOARD ASS'Y. (A1)



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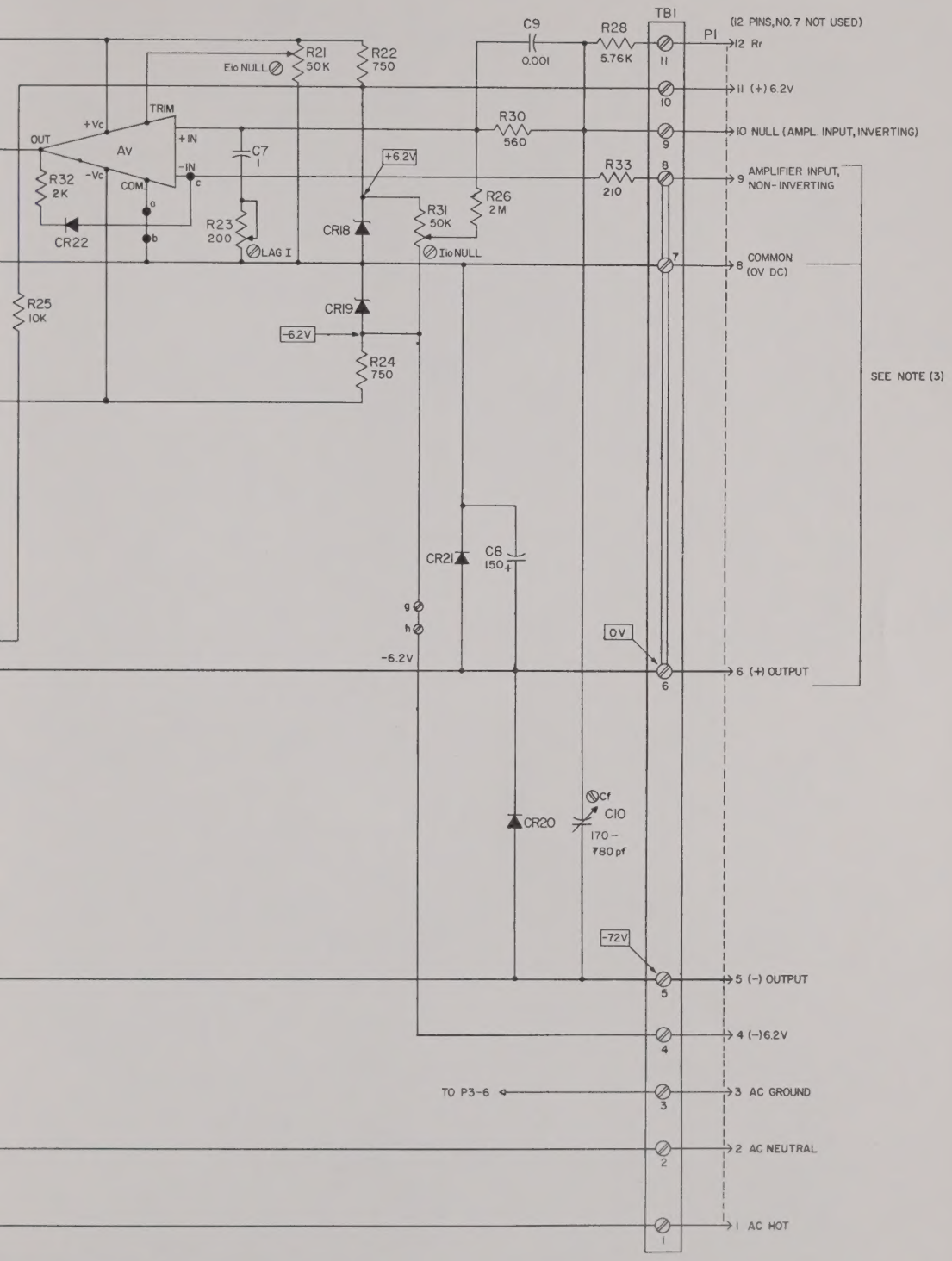
Data subject to change without notice
PATENT NOTICE: Applicable Patent Nos.
will be supplied on request

NOTES

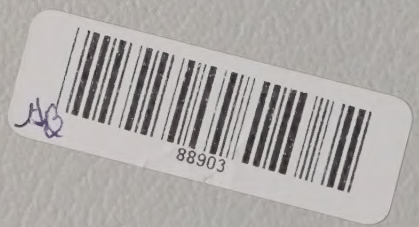
1. RESISTOR VALUES IN OHMS, K = 1000
2. CAPACITOR VALUES IN MICROFARADS
3. LINKS ON TB1 MUST BE CLOSED AS S
ON P1 MUST BE SHORTED FOR STANDA
4. CONDITIONS FOR LISTED VOLTAGE RE
A) LINE AT 115 VAC, 60 Hz.
B) METER: 20K OHMS PER VOLT.
C) REFERENCE POINT: COMMON (+ SE
D) MAXIMUM OUTPUT VOLTAGE, PRO
AND CONNECTING APPROPRIATE R
E) READINGS SUBJECT TO NORMAL
5. MAIN TRANSFORMER CONNECTIONS



LESS INDICATED OTHERWISE
WN, OR PINS (8), (9) AND (6)
OPERATION.
NGS:

)
D BY CLOSING (10) AND (11) ON TBI
BACK RESISTOR FROM (9) TO (5) ON TBI.
PONENT TOLERANCES
WN FOR 115 V AC OPERATION.

FIG. 6-3 MAIN SCHEMATIC, MODEL OPS 72–0.3 B



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